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A Comparison of the Pulmonary Function of Older Endurance Athletes with Age-Matched Sedentary Controls

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A COMPARISON OF THE PULMONARY FUNCTION OF OLDER ENDURANCE ATHLETES WITH AGE-MATCHED SEDENTARY CONTROLS

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DEFINITION OF TERMS

Allometric Model – A mathematical procedure used to establish a proper relationship between a body size variable and some other related factor of interest. The technique is used to provide proper statistical adjustment to evaluate the relative contribution of diverse independent variables.

BMI – Body mass index is a measure derived from body mass and stature used to access the "normalcy" of a person's body weight. BMI = weight (kg) / height (m^2).

BTPS – Body Temperature (37C), pressure, saturated with water vapor.

DLCO- A test that measures the lung's capacity to diffuse carbon monoxide (CO). The diffusing capacity is equal to CO uptake per unit time divided by the mean pressure of gradient for CO between alveolar gas and capillary blood.

ERV- Expiratory Reserve Volume. The maximum amount of air that can be forcefully exhaled after a quiet expiration has been completed, i.e., from the end-expiratory position.

$FEF_{25\%-75\%}$ - Forced Mid-Expiratory Flow also know as the Mean Mid Expiratory Flow – The mean amount of flow measured during the middle half of the forced vital capacity maneuver.

FEV_1- Forced Expiratory Volume One Second. - The amount of volume (liters) measured in the first second of the forced vital capacity maneuver.

FEV1/FVC%. – The ratio of the FEV1 to FVC used in the analysis of different types of lung disease, i.e., restrictive versus obstructive.

FEV_3- Forced Expiratory Volume Three Seconds. - The amount of volume (liters) measured in the beginning three seconds of the forced vital capacity maneuver.

Flow-Volume Loops. – Graphic representation of the relationship between airflow and lung volumes during maximal expiratory and inspiratory maneuvers.

FVC- Forced Vital Capacity. – The maximum volume of air (liters) that is exhaled as rapidly, forcefully and completely as possible form the point of maximum inhalation.

FRC – Functional Residual Capacity. – The volume of air that remains in the lungs at the end of a normal expiration.

IC – Inspiratory Capacity. – The maximum amount of air that can be inhaled from the end-expiratory position. It is comprised of the tidal volume (TV) and the inspiratory reserve volume (IRV).

IRV – Inspiratory Reserve Volume. – The maximum amount of air that can be inhaled from the end of a tidal volume (TV) inhalation.

MEP – Maximum Expiratory Pressure. – The maximum pressure that can be generated by a forceful expiration from total lung capacity measured in mmH_2O. Used to measure expiratory muscle strength.

MIP – Maximum Inspiratory Pressure. – The maximum pressure that can be generated by a forceful inspiration from residual volume (RV) measured in mmH_2O. Used to measure inspiratory muscle strength.

MVV – Maximum Voluntary Ventilation. - The volume of air that can be exhaled during 12 seconds of rapid, deep breathing. The actual volume is extrapolated to one minute and measured in liters/minute.

PEF – Peak Expiratory Flow. – The maximum amount of flow at peak expiration measured in liters per second or liters per minute.

RV – Residual Volume. – The volume of air that remains in the lungs after a maximal expiratory effort.

RV/TLC% - Residual Volume to Total Lung Capacity ratio. – The ratio of air that remains in the lungs after a maximal expiration (RV) to the total capacity of the lungs. Expressed as a percent and used to determine normal versus abnormal lung function.

Spirometery. – A method employing various types of apparatuses used to measure the dynamic volumes and flows of the lungs.

TLC- Total Lung Capacity. – The total volume of air contained in the lungs at the end of a maximal inspiration.

TV – Tidal Volume. – The volume of air that is drawn into the lungs during inspiration from the end-expiratory position and also leaves the lungs passively during expiration during quiet breathing.

VC – Vital Capacity. – The volume of air that is exhaled by a maximal expiration after a maximal inspiration.

VO_2max. - The maximum amount of oxygen that an individual is able to consume in a given amount of time at a measured workload. Measurement used to access aerobic fitness levels.

ABSTRACT

Purpose: To compare the pulmonary function of older runners with non-runners and also the population norms. **Method:** 40 males ages 45 to 65 were compared for respiratory muscle strength, spirometry and maximum voluntary ventilation. Univariate and multivariate analysis ($p < 0.05$) were used to determine differences **Results:** No significant differences in age, height, or respiratory muscle strength were found. A significant difference was found for weight and BMI with the non-runners having greater values. The dependent variables of FVC, FEV1, $FEF_{25-75\%}$, PEF, and MVV resulted in a significant difference with the runners having greater values. A significant difference was also found for pulmonary function between runners and the general population. **Conclusion:** Continued and habitual aerobic exercise in the form of running in 45 to 65 year old men resulted in pulmonary function values that were significantly greater than those of the non-runners and also greater than population norms.

INTRODUCTION

Numerous studies have shown that individuals who continue to engage in aerobic type endurance exercise throughout their lives can attain and maintain levels of physiological and aerobic fitness that compare with much younger individuals. Hagberg, Yerg, and Seals (1988) found that it was not unusual for some older athletes to exhibit physiological capacities that were equal to if not better than those of young untrained individuals. Several studies have shown that VO_2 max, maximal stroke volume, and body composition measures of older endurance trained athletes were superior when compared to their sedentary peers (Hagberg, Allen, Seals, Hurley, Ehsani & Holloszy, 1985; Heath, Hagberg, Ehsani, 1981). Other physiological parameters of older endurance athletes such as glucose tolerance, insulin sensitivity, and plasma lipid levels have also been shown to be equal to younger individuals and greater than those found in their sedentary peers (Allen, Seals, Hurley, Ehsani, & Hagberg, 1985; Seals, Allen, Hurley, Dalsky & Ehsani, 1984; Seals, Hagberg, Allen, Hurley, Dalsky, Ehsani & Holloszy, 1984). It is clear from the body of scientific evidence that exists on older aerobic athletes that many physiological benefits can be expected from continued participation in aerobic exercise.

Pulmonary function is one of the physiological parameters where one might logically expect to find superior values in older endurance-trained athletes relative to their peers. The logic being that superior pulmonary function should be a contributing factor to the elevated maximal oxygen consumption (VO_2 max) seen in many older endurance-trained athletes (Heath et al., 1981). By definition endurance athletes practice aerobic exercise. Aerobic type endurance exercises are activities that involve the use of large muscle groups for extended periods of time. Examples include such activities such as cycling, swimming, cross-country skiing, rowing, in-line skating, jumping rope, bench-stepping, stair climbing and running. Any of these activities preformed with sufficient duration, intensity, and frequency will elicit cardiovascular or aerobic improvement that leads to an improved $VO_{2\ max}$ (Brahler & Blank, 1995; Lotgering, van Doorn, Struijk, Pool & Wallenburget, 1991; Wallick, Porcari, Wallick, Berg, Brice & Arimond, 1995). Aerobic fitness is traditionally measured as $VO_{2\ max}$ or the maximum amount of oxygen that an individual is able to consume in a given amount of time at a measured workload. The physiologic components that contribute to VO_{2max} include hemoglobin concentration, blood volume, cardiac output, peripheral blood flow, aerobic metabolism and pulmonary ventilation (McArdle, Katch & Katch, 2001). Pulmonary ventilation is one of the main physiologic components of $VO_{2max.}$ The minute ventilation (V_E) or volume of air consumed is one of the parameters used to measure VO_{2max} via open-circuit spirometry. Any increases in the measured minute ventilation (V_E), a direct measure of pulmonary ventilation, will result in higher VO_{2max} scores. When these two facts are considered it would seem reasonable to assume that superior pulmonary function should be a contributing factor to the higher than predicted VO_{2max} found in endurance athletes. Many factors have been shown to contribute to the enhanced aerobic capacity of highly trained athletes. Increases in blood plasma volume, heart stroke volume, cardiac output, oxygen extraction, improved blood flow and distribution, and improved buffering of lactate all contribute to the increased aerobic capacity of trained athletes (McArdle, Katch & Katch, 2001). The role pulmonary ventilation plays in contributing to improved aerobic capacity has not been fully resolved. While improvement in pulmonary function has been shown to enhance the ability to sustain high levels of ventilation it has shown little or no effect on maximum static or dynamic lung functions (Boutellier, 1998; Johnson, Saupe & Dempsey, 1992). Several studies have shown little or no improvement in pulmonary function with aerobic training. (Babcock & Dempsey, 1994; Grimby & Soderholm, 1963). However the majority of those studies were executed with young subjects whose ages were such that they were at or near their physiological peak. Another way of thinking about this is that the young athletes were either still physically maturing or had just reached their physical maturity and as a result their physiological parameters were at or near peak and had not yet begun to decline. Few studies have looked at the lung functions of older endurance athletes. The few that have looked at the lung functions of the older endurance athlete were either conducted with a small number of subjects or in some instances just singular case studies (Faria & Frankel, 1977; Maud, Pollock, Foster, Anholm, Guten, Al-Nouri, Hellman & Schmidt, 1981; Webb, Urner & McDaniels, 1977). Pulmonary lung function when measured as forced expiratory function has been repeatedly shown to decrease with advancing age in humans (Babb, 1999; Pfitzenmeyer, Brondel, D'Arthis, Lacroix, Didier & Gaudet, 1993; Schmidt, Dickman, Gardner, & Brough, 1973). Since pulmonary function is a physiological parameter that declines with aging it is possible that endurance aerobic exercise will prevent or slow the natural decline when practiced over an extended time period.

Pulmonary lung function is commonly assessed by spirometry. The test results are usually compared against population norms derived from regression equations resulting from large-scale studies. Predictive norms for pulmonary functions have been established for many different population groups (Birath, Kjellmer & Sandqvist, 1963;

Black & Hyatt, 1969; Crapo, Morris, Clayton & Nixon, 1982; Ferris, Anderson & Zickmantel, 1965; Gison, Pride, O'Cain & Quagliato, 1976; Goldman, & Becklake, 1959; Grimby & Soderholm, 1963, Grimby & Saltin, 1966; Kory, Callahan, Boren & Syner, 1961; Morris, Koski & Johnson, 1971; Needham, Rogan & McDonald, 1954; Norris, Shock, Landowne & Falzone, 1956). Normative values for pulmonary lung functions are established after testing very large numbers of individuals with similar characteristics and then deriving predictive equations through the use of regression statistics. The major grouping characteristics for pulmonary functions include height, weight, age, sex, and ethnicity. Subjects are tested and their scores are reported as percent of predicted. The American Thoracic Society (1987) is the governing body that sets the standards for pulmonary function testing.

Lung volumes are divided into the following four divisions, tidal volume (TV), inspiratory reserve volume (IRV), expiratory reserve volume (ERV), and residual volume (RV). These four volumes comprise the four capacities of the pulmonary system. The total lung capacity (TLC) contains all four volumes and is the maximum amount of lung volume. The vital capacity (VC) is the next largest and is comprised of three lung volumes, the IRV, TV, and the ERV. The inspiratory capacity (IC) is comprised of two volumes, the IRV and TV. The functional reserve capacity (RFC) is comprised of two volumes, the ERV and the RV. Parameters measured to assess lung function with simple spirometry include forced vital capacity (FVC), forced expiratory volume one second (FEV_1), and three seconds (FEV_3), ratio of FVC/FEV_1, forced expiratory mid-flow (FEF_{25-75}), maximum voluntary ventilation (MVV), and peak expiratory flow (PEF). Respiratory muscle strength is commonly assessed via negative inspiratory force (NIF) and positive expiratory force (PEF) (Spearman, Sheldon & Egan, 1982).

Purpose

The primary purpose of this study was to compare the pulmonary function of older endurance trained athletes with that of age-matched non-aerobic exercising controls. The measured values of both groups were compared to established normative values. The results were used to determine if the practice of continuous aerobic exercise in the form of endurance running had any attenuating affect on the natural decline of pulmonary function. The decline of pulmonary lung volume and function with age is a well-documented phenomenon (DeLorey & Babb, 1999; R.J. Knudson, Clark, Kennedy D.E. Knudson, 1977). A secondary purpose was to determine if long-term aerobic exercise in the form of endurance running resulted in greater then expected pulmonary function for runners when compared to the general population.

Hypotheses

The first hypothesis of this study was that older individuals between the ages of 45 and 65 years of age that had practiced continuing endurance running for a minimum of 10 years would have significantly greater pulmonary function than age-matched individuals of similar characteristics who had not practiced endurance running or other types of aerobic exercise. Specifically it was expected that the older endurance-trained athletes would have statistically significantly greater forced vital capacities (FVC), forced expiratory volumes at one second (FEV_1), forced mid expiratory flows (FEF_{25-75}), maximum voluntary ventilation (MVV), and greater negative inspiratory force (NIF) and positive expiratory force (PEF) when compared to the control subjects. The second hypothesis was that the runners would have significantly greater ($p < 0.05$) pulmonary function values then the general population when matched for age, height, sex, and race as predicted by Knudson's (1983) pulmonary function prediction equations.

Limitations

Limitations that may have affected the results of this study included but were not limited to the following possible reasons. A small sample size of only 20 subjects in each group limited the power of the study. Factors such as outlier values and unknown lung disease of any of the subjects could have confounded results. Inaccurate self-report information may also have affected results. Finally the effort dependent nature of pulmonary function testing may have introduced error. Every effort was made to minimize error. The spirometer was calibrated each day before testing (see Appendix D). Only one person, the principal investigator, performed all testing. Extensive practice testing was performed before the study began to familiarize the tester with the equipment and procedure. Three different pretest subjects were tested and then retested to establish test reproducibility. Results were within +/- 3% for all three cases. Validity was established by using proven, accepted methods and standards mandated by the American Thoracic Society for pulmonary function testing. Sample spirometry reports can be found in Appendix E.

LITERATURE REVIEW

The decline of certain pulmonary function parameters with age is a well-documented phenomenon that has been the subject of many scientific studies. The exact mechanisms responsible for this phenomenon have only been partially accounted for and explained in the research literature. The complex nature and multitude of variables involved in separating the singular effects of aging on pulmonary functions from all other factors such as environment, disease, genetics, and physical activity has complicated efforts to identify the affects due solely to aging.

A retrospective review by Knudson et al., (1977) examined the pulmonary function and aging literature. The authors found little consistency or agreement of findings in the literature related to the affects of aging upon pulmonary function. Some of the studies reviewed reported finding age related affects, some reported not finding any age related affects, and some were inconclusive in their findings. Frank, Mead and Ferris (1957) found a loss of elastic recoil with aging but could not show that the loss of elastic recoil was due solely to aging. Contrary to results published by Permutt and Martin (1960) who found no connection between loss of lung elasticity and aging. A subsequent study by Turner, Mead, and Wohl (1968) showed significant results indicating that loss of elastic recoil was related to aging. According to Knudson et al. (1977) the problems with these studies and several others from the same era were the lax criteria for subject selection. Subjects were not screened closely enough for past history of respiratory disease or current or past smoking habits any of which could have confounded the results. As a result of these contradictory findings Knudson et.al (1977) designed a study that attempted to eliminate and control for variables not solely related to age. Initial screening included over three thousand subjects from a longitudinal epidemiological study on obstructive lung diseases with the final sample size reduced to 51 subjects. Stringent protocols eliminated all subjects that had any history of lung disease, smoking, or abnormal pulmonary functions. The remaining subjects where then tested and determined to be alpha-1 antitrypsin MM phenotypes. People who are not alpha-1 antitrypsin MM phenotypes have a greater chance of certain inherited emphysema such as lung diseases. Final selection resulted in 73 eligible subjects with 51 full studies being completed. The subjects were placed into three different age groups delineated at 25-35, 36-64, and 65-75. Spirometry and plethysmographic studies were conducted to produce pressure volume curves and determine lung volumes. The results showed the loss of elastic lung recoil existed with aging and was more significant (p=0.015) at higher rather than a lower lung volumes. The author's of this study concluded that while there was a statistically significant aging effect on lung function it was not profound and was less then half that reported by previous studies.

DeLorey and Babb (1999) investigated the progressive mechanical ventilatory constraints associated with aging. Forty-five subjects of ages ranging from 36 to 90 years had their pulmonary functions measured each minute while performing graded cycle ergometry to exhaustion. Minute ventilation (VE), lung volume, expiratory airflow limitation (EAFL), age and gender were the measured variables. The results showed a significant increase in end-expiratory lung volumes (EELV) that increased progressively with age. The normal decrease in EELV usually seen in young, healthy subjects during the early stages of exercise was not present in the older subjects. DeLorey and Babb

(1999) concluded that aging showed significant ($p<0.05$) progressive mechanical ventilatory constraints that were significant during exercise. In a related study Babb and Rodarte (2000) investigated the determinates of maximal expiratory flow (MEF) with aging. MEF was studied in young, middle age, and elderly subjects at 60. 70, 80, 90, and 100% of total lung capacity. All subjects were screened for history of respiratory diseases. Standard spirometry and plethysmographic tests were performed on all subjects. The results showed significant ($p<0.05$) declines related to aging for maximal expiratory flow (MEF), static lung elastic recoil pressure (Pst), and minimal pressure for maximal flow (Pcrit). Decreases in MEF were proportional to decreases found in Pst. Babb and Rodarte (2000) indicated that the major finding of their study was that decreases in MEF could be explained almost entirely by decreases in Pst. Babb and Rodarte (2000) also found just as Knudson et al. (1977) had, that the changes in Pst at 90% and 100% of total lung capacity (TLC) were much smaller for men than for women of similar age. Greater respiratory muscle strength was suggested as a possible explanation for this finding.

Further evidence that age-related changes in pulmonary architecture that included decreased elastic lung recoil, increased stiffness of chest wall, and reduced respiratory muscle strength result in decreased pulmonary function was shown by Dempsey and Seals (1995). The pressure generated by the recoil of the lung is closely related to the intra-airway pressure and as elastic recoil declines with age the result is airway closure at higher lung volumes. The resulting decrease in expiratory flow coupled with decreased respiratory muscle strength accounts for the diminishing pulmonary functions, particularly FEV_1, seen in the aging lung. A seven-year longitudinal study by Nihon, Kyobu, Shikkan, Gakkai and Zasshi (1997) measured the forced vital capacity (FVC) and forced expiratory volume one second (FEV_1) of 243 healthy Japanese men. They compared their findings with predicted values derived from regression equations generated from a previously conducted large cross-sectional study of Japanese adults. The results of their study showed average declines of only 22 mls per year for FVC and 11 mls per year for FEV_1. The predicted values for FVC and FEV_1 generated from the regression equations were as much as 150% to 200% greater then the actual values.

Amara, Koval, Paterson and Cunningham (2001) used an allometric model to determine what factors were important to the decline in FEV_1 found in subjects aged 55 to 86 years. The study was designed such that there were approximately 35 men and 35 women in each 5-year age grouping (55-59, 60-64, etc.). All subjects had to be capable of walking a distance of 80 meters and living independently. Spirometry and handgrip strength tests were performed on all subjects. Anthropometric measures of height, weight, and skinfold thickness were used to calculate body mass index (BMI) and fat-free mass (FFM) of subjects. Spirometry was limited to collecting forced expiratory volumes one-second ($FEV_{1)}$ using American Thoracic Society guidelines. Physical activity was determined by administration of the Minnesota Leisure Time Physical Activity questionnaire (Taylor, Jacobs, Schucker, Knudsen, Leon & Debacker, 1978) and grip strength measured via a hand held dynamometer. Regression analysis was used to examine the relationship between variables. The variables of height, age, sex, percent body fat, FFM, grip strength, and physical activity were placed in an allometric model proposed by Nevill and Holder (1995) to determine their influences on FEV_1. The following equation accounted for 47.3% of the variance found in FEV_1: ($\ln FEV_1 = 1.578 \ln height + 0.544 \ln FFM + 0.010 \ln PA - 1.338 - 0.012 age - 0.083 smoking\ status +$

lnε). FFM, grip strength and physical activity were incorporated as power functions in the model. Amara et al. (2000) found a cross-sectional decline of 50 ml per year for men and 43 ml for women. As a group the subjects with greater FFM ($p<0.01$) and greater handgrip strength ($p<0.01$) had significantly higher FEV_1 values. Subjects with higher levels of physical activity showed a non-significant trend toward higher FEV_1 values. The major finding of this study was that FFM had the greatest influence of FEV_1 and demonstrated the contribution muscle mass has on pulmonary function in older subjects.

Chen and Kuo (1989) examined the relationship between respiratory muscle function and age, sex and other factors. They investigated 160 subjects, 80 female and 80 male, ranging from 16 to 75 years of age. Maximal inspiratory and expiratory pressures were measured to determine respiratory muscle strength along with standard spirometry to determine volumes and flows. Their findings showed that there was a significant decline ($p<0.05$) in respiratory muscle strength and pulmonary function associated with aging. They also found a significant positive ($r = 0.29$) relationship for inspiratory muscle endurance and physical activity.

In general the majority of the recent pulmonary function literature indicates that pulmonary function declines with age. The primary decrease is due to loss of lung elastic recoil that leads to decreased lung volumes and flows. FVC and FEV_1 have been shown to begin decreasing as early as the age of 40 and continuing to decrease with advancing age. Although a substantial number of studies have been done on the pulmonary function of normal, healthy and unhealthy older subjects, very little data exist on older endurance athletes. The few studies that have been done were either case studies or studies involving small numbers of subjects and quite often had conflicting results and conclusions.

Hagberg et al. (1988) conducted a study with forty subjects. They compared the lung volumes and pulmonary functions of older endurance trained athletes against those of age-matched sedentary controls, young athletes, and young untrained athletes. Their purpose was to determine if aerobic training had any affect on the age-associated changes in lung volumes and pulmonary functions. They found a significant difference ($p<0.05$) in the $VO_{2\ max}$ between the older athletes and their age-matched sedentary controls. Maximal oxygen uptake (Vo_{2max}) was 37% greater in absolute terms and 85% greater when expressed as per kilogram of body weight in older athletes when compared to their untrained peers. The older athletes weighed on average 20 kilograms less than the control subjects, thus accounting for the large difference between absolute and relative values. All lung volume and pulmonary variables were similar for these two groups on an absolute basis. When values were normalized for height the athletes who were 12 centimeters shorter on average had significantly ($p<0.05$) larger values for vital capacity, FEV_1, and total lung capacity. The Ve_{max} of the older athletes was 22% higher then their untrained peers however both groups had similar maximum voluntary ventilation scores resulting in a higher Ve_{max} to MVV ratio for the older athletes. The same trend was found when the young athletes were compared to their age matched sedentary controls. Maximum voluntary ventilation (MVV) and residual volume (RV) were also larger but not significant in the older athletes. It is of interest to note that there were no differences found between the young athletes and their age-matched sedentary controls on either absolute or relative terms for any static lung volumes. RV and RV/TLC % were the only variable larger in the older athletes compared to the younger athletes and all other lung volumes and pulmonary functions were lower except TLC, which was the same for all groups. The older athletes were the only group who had pulmonary functions that were significantly greater than their age-predicted norms.

Previous to this study several other studies had compared the pulmonary function values of older endurance athletes to published age-related regression equation predicted norms. While results have been somewhat mixed a general consensus exists that TLC, VC, FEV_1, and MVV are larger in older endurance trained athletes then in age-matched peers (Grimby et al., 1966; Heath et al., 1981; Maud et al., 1981; Webb et al., 1977; Wilmore, Miller & Pollock, 1974). The problem with most of these studies was small sample size; in some instances, they were only single case studies or poor subject selection. Hagberg et al. (1988) used (N = 40) total subjects with 10 subjects in each age group and concluded from their findings that the older athletes had larger lung volumes and better pulmonary functions than their age-matched sedentary controls. They also found no significant differences between lung volumes and pulmonary functions of the younger athletes and their age-matched controls. The older athletes were the only group in the Hagberg study whose pulmonary function values were substantially greater then their predicted norms. Their assumption was that the type and duration of endurance exercise practiced by the older athletes had slowed the rate of deterioration of pulmonary function normally associated with aging. A further assumption made was that a percentage of the decline in lung volumes and pulmonary functions normally associated with aging might be attributed to the deconditioning that usually occurs with aging and not completely and solely related to aging alone. Hagberg et al. (1988) hypothesized from their results and the results of other studies that the improvement of pulmonary function found in older endurance athletes might be attributed to enhanced respiratory muscle function as a result of practicing aerobic exercise.

Belman and Gaesser (1988) tested twenty-five elderly subjects, ages 65-75 years, to determine if declining pulmonary function impaired exercise capacity. Subjects were tested for exercise capacity and ventilatory muscle endurance before and after an eight-week training period. Training consisted of isocapnic hyperpnea exercise done 30 minutes per day and four times per week for eight weeks. The trained group showed a significant increase ($p < 0.01$) in maximal sustained ventilatory capacity (MSVC). The MSVC for the trained group improved from 71.9 ± 26.4 to 86.9 ± 20.9 liters per minute whereas the control group (no training) showed no change (66.3 ± 22.5 to 65.1 ± 22.1 liters per minute). The trained group also showed a significant increase ($p < 0.01$) in maximal voluntary ventilation (MVV) from 115 to 135 liters per minute. It was noted that there was no increase in either group for maximum O_2 uptake, maximum CO_2 uptake, or MVV during the incremental exercise test. A possible explanation was the subjects training was limited to lung exercise and did not involve any walking or running that would have improved their leg strength and endurance and resulted in higher VO_{2max} scores.

Cordain, Glisan, Latin, Tucker, and Stager (1987) conducted a study of 101 male runners ranging in ages from 16 to 58 years of age. The purpose of the study was to investigate the long-term effects of running upon pulmonary function. Maximal inspiratory and expiratory pressures, pulmonary volumes and capacities and anthropometric parameters were measured. The results showed no significant difference ($p < 0.05$) in mean $P_{E\,max}$ for age, suggesting that expiratory muscle strength did not decline significantly after maturity in runners. However mean $P_{I\ max}$ showed a significant trend ($p < 0.001$) for declining with age. No significant trend ($p < 0.05$) was found for decline in FVC related to age except for in the 50-59 year age group. Six different prediction equations were used to compare against observed values. Comparison with five of the six equations resulted in significantly larger ($p < 0.05$) FVC values for the runners. It was noteworthy that the predicted FVC value from Morris et al. (1971) yielded similar results as the measured values. The Morris et al. (1971) study was conducted with a large number of subjects and excluded all smokers. Morris etal. (1971) concluded that while running probably does not cause increases in FVC it appeared to have some effect in slowing the decline normally seen associated with aging.

In contrast to the studies that have shown positive correlations to aerobic exercise and lung function, McClaran, Babcock, Pegelow, Reddan, and Dempsey (1995) conducted a longitudinal study over six years that examined the pulmonary functions of 18 older adult subjects (ages 67 to 73 years). McClaran et al. questioned the results of studies that showed improved and superior lung function in older athletes. They reasoned that since there was no evidence to support that long-term aerobic training had any significant beneficial effects upon the pulmonary function of young adults why would one expect to find a different result for older athletes. They concluded from their findings that habitual physical activity and high aerobic capacity did not modify the normal deterioration of pulmonary lung volume and function associated with aging either at rest or during exercise. During the six-year period TLC, FRC and diffusion capacity (DLCO) did not change, but FVC (-11%), FEV_1 (-13%), maximal volitional flow rates (-13%) decreased while RV (+13%) and closing capacity/TLC% (+13%)increased. The results also showed these values were greater than what would be predicted from cross-sectional norms. This study retested 18 subjects 6 years after initial testing. The subjects mean age increased from 67.0 $\pm$ 1.2 to 72.9 $\pm$ 1.3 years between tests. Ten of the eighteen subjects swam, biked, walked, or ran on average of three times per week. The other eight subjects were competitive masters runners. A significant positive correlation was found between the subject's age and the magnitude of change in RV, DLCO and FEV_1 (r = 0.48-0.61, P<0.05) showing the older the age at the beginning and end of the study the greater the reduction in resting lung function over the six year study. It was not stated but it would have been of informative value to know if the results were different between the master runners and the rest of the subjects. The small sample size (18), large variance in age (62 to 82 years) and variety of physical activity (walkers to master runners) limits the interpretation of the findings. One possible reason for the conflicting findings between the Hagberg et al. (1988) and the McClaran et al. (1995) was the use of two different types of study designs. The Hagberg study was cross-sectional while the McClaran study was longitudinal. Another possible explanation could be the difference in age between the two groups. The mean age of the older athletes were 65 $\pm$ 3 for the Hagberg study and 72.9 $\pm$ 1.3 for the McClaran study.

Chen et al. (1989) investigated the relationship between respiratory muscle function and age, sex and other factors. Their study involved 160 subjects comprised of men, women, smokers, non-smokers, and both young and old subjects. The results showed inspiratory muscle strength was greater in physically active men then in sedentary controls and also that respiratory muscle and pulmonary function decreased with age.

A summary table of the relevant literature can be found in Table 1. As indicated, very few investigators have studied the pulmonary function of older endurance athletes and the majority were either case studies or of small sample size. The few studies that were published that had reasonable a number of subjects have resulted in conflicting results. Further investigation can help in answering the question does long term participation in aerobic exercise have any protective ability in slowing the decline of pulmonary functions normally associated with aging?

Table 1. Summary of Research Examining Pulmonary Function of Adults

Source	Gender	N	Age (yr)	BW (kg)	Ht (m)	BMI (BW/Ht^2)	FVC (liters)	FEV_1 (liters)	NIF (cmH_2O)	PEF (cmH_2O)	MVV (l/min)	PEF (l/min)	VC (liters)	VO_2 (ml/kg/min)
Yerg	M_R	14	63.0	67.9	1.72	23.0	---	---	---	---	163.1	---	---	52.1
(1985)	M_S	14	63.0	83.2	1.76	26.9	---	---	---	---	143.5	---	---	27.6
Cordain	M	25	34.0	73.1	1.75	23.9	5.36	---	122	202	---	---	---	---
(1987)	M	8	55.0	77.9	1.78	24.6	4.68	---	111	178	---	---	---	---
Hagberg	M_R	10	65.0	64.5	1.71	22.1	---	3.52	---	---	150	---	4.88	50.0
(1988)	M_S	10	66.0	85.7	1.83	25.6	---	3.49	---	---	153	---	4.74	27.0
Chen	M	20	34.4	62.8	1.65	23.1	---	---	116.5	136.6	---	---	---	---
(1989)	M	20	53.9	62.8	1.65	23.1	---	---	92.8	133.6	---	---	---	---
McClaran	M, F	30	67.0	65.2	1.71	22.3	---	3.18	---	---	127.2	9.32	4.16	45.3
(1995)	M, F	18	72.9	65.5	1.7	22.7	---	2.78	---	---	111.1	8.04	3.72	40.3
Babb	M	7	38.3	81.8	1.79	25.5	5.54	4.37	---	---	194	10.8	---	---
(2000)	M	10	54.0	90.2	1.78	28.5	5.06	4.04	---	---	168	10.1	---	---
Amara (2000)	M	181	70.4	77.7	1.73	26.0	---	2.55	---	---	---	---	---	---
Eastwood	M_R	6	37.5	70.8	1.75	23.1	5.8	4.7	---	---	---	---	---	58.5
(2001)	M_S	6	28.0	91.8	1.80	28.3	5.4	4.4	---	---	---	---	---	38.6

Note: M_R =male runner, M_S = male sedentary for Yerg, Hagberg and Eastwood. Selected age group data extracted from Cordain, Hagberg, Chen, Babb, and Amara.

METHODS

This section consists of detailed descriptions of the subject selection, data collection methods, and data analysis. Spirometery was used to compare the pulmonary function of older endurance trained aerobic athletes with that of age-matched non-aerobic exercising controls. All subjects were measured for height and weight with BMI's calculated. Spirometery tests included measurement of FVC, FEV_1, FEF_{25-75}, and PEF. MVV, negative inspiratory force and positive expiratory force were also measured. Statistical analysis was used to determine if significant differences in pulmonary function exist between the athletes and the controls.

Subjects

The study collected and compared the pulmonary function data of two groups of individuals. All subjects participating in the study were apparently healthy, adult males between the ages of 45 and 65. They were non-smokers of tobacco without any history of pulmonary diseases such as asthma or emphysema. The test subjects were men who have exercised regularly by jogging or running most of their adult lives. The control subjects were men of the same age who had not exercised regularly, particularly by jogging or running, most of their adult lives. Twenty subjects comprised each group. Since the study only involved non-invasive, non-strenuous pulmonary function testing, medical approval by the subject's physician was not required. Approval for the study was obtained from the University of New Orleans's Committee for the Use of Human Subjects (see Appendix A). Written informed consent was obtained from all subjects after they were informed of the possible dangers and purpose of the study (see Appendix B). The test subjects were Caucasian male adults ranging in age from 45 to 65 years of age. They were runners who have run consistently for at least the last 10 years and averaged a minimum of at least 20 miles per week during the last calendar year. Self-report was used to establish the subjects running history. Exercise subjects were recruited from the New Orleans Track Club, Cajun Road Runners, and other local area runners. An explanatory letter, and a qualifying questionnaire along with a self-addressed postage paid return envelope was handed out or mailed to all potential study participants.

The control subjects were Caucasian male adults ranging from 45 to 65 years of age. Controls were age-matched and recruited from the general population. An extended history of any type of aerobic exercise including but not limited to cycling, swimming, cross-country skiing, rowing, in-line skating, jumping rope, bench-stepping, stair climbing or running was used to exclude subjects from the study. Potential control subjects were recruited from local area softball and bowling leagues as well as local area social organizations.

Testing was begun once a subject had been identified and qualified. An activity questionnaire was used to assess general health and activity level (see Appendix C). Each subject was scheduled for a single testing session that lasted no more than 30 minutes. Anthropomorphic measurements of height and weight were taken and recorded.

Measures

Each subjects weight was measured with a Healthometer model HAP400 professional dial scale that was calibrated with a standard 10-kilogram weight before each session. Weights were recorded in kilograms to the nearest 0.1-kilogram. Subjects were required to stand on the scale with their weight evenly distributed between both feet and with arms hanging freely at their sides. Two measurements of weight were taken for each subject and if the measurements varied by more than 0.1 kilogram the measurements were repeated until the standard was met.

Height was measured using a Secca model 214 “Road Rod” portable stadiometer. Subjects were required to stand erect with their weight distributed evenly between both feet, arms hanging freely at their sides, and palms facing the thighs. Subjects were required to place ankles and or knees together so that they touch one another if possible. The subject’s head was then placed in the Frankfurt Horizontal plane and then were asked to inhale to full lung capacity without altering their stance. The headboard was then lowered with enough pressure to compress the subject’s hair and make contact with the most superior part of the head. The measurements were recorded in centimeters to the nearest 0.1-centimeter. Two measurements of height were taken for each subject and if the measurements varied by more than 0.1 centimeter the measurements were repeated until the standard was met.

Body mass index was calculated with the collected height and weight measurements using the standard formula of BMI = body mass (weight in kilograms) divided by stature (height in meters squared) or (BMI = kg/m^2).

Pulmonary Function Tests

Each pulmonary function test was fully explained and demonstrated to each test subject. Once the subject acknowledged understanding of the procedure they were allowed two practice maneuvers before recording of test results began. Only pulmonary function test results that met all requirements set forth by the American Thoracic Society (1987) were accepted and included as test data. The following specific pulmonary tests were conducted upon each subject. Maximum inspiratory and expiratory pressures (MIP, MEP), flow-volume loops, and maximum voluntary ventilation (MVV) comprised the three pulmonary function tests that were performed upon each subject.

Negative inspiratory force (NIF) and positive expiratory force (PEF) were measured using a Technika Scientific Equipment Model 840080 manometer. To measure the PEF the subject was instructed to inhale completely to total lung capacity and then exhale as forcefully as possible into the pressure gauge. Each test was performed 3 times. The test that resulted in the greatest value and was also held for a minimum of 1 second was taken and recorded as the subject's PEF and was recorded in positive centimeters of water (cmH_2O). NIF was obtained by having the subject first exhale completely to residual volume followed by inhaling as forcefully as possible. The test that resulted in the greatest value and was also held for a minimum of 1 second was taken and recorded as the subject's NIF and was recorded in negative centimeters of water (cmH_2O).

Flow-Volume Loops were measured with a Puritan Bennet Renaissance II portable spirometery system. The Renaissance spirometer was calibrated before testing began on each subject and performed in accordance with both the manufacturer's and the American Thoracic Society's (1987) guidelines. Forced vital capacity (FVC), forced expiratory capacity one second (FEV_1), forced expiratory mid-flow ($FEF_{25\%-75\%}$), and peak expiratory flow (PEF) were the pulmonary function values that were measured and recorded from the flow-volume loop tests. The subject was required to stand erect and wear a nose clip for each flow-volume test. They were instructed to place the mouthpiece fully into their mouth so the end of the mouthpiece was at least 1 inch beyond the exterior of their lips and to form as tight a seal as possible by keeping their mouth closed and exerting moderate force with their lips around the mouthpiece. The subject then took 3 to5 easy resting breaths before being instructed to inhale quickly to maximal lung capacity followed by immediately exhaling with maximum force for at least six seconds and ending with a final inhalation back to maximal lung capacity. In accordance with the standards and guidelines set forth by the ATS regarding acceptable results for flow-volume loops each subject performed a minimum of 3 trials. However, each subject was allowed as many trials as necessary to obtain 2 trials that had results that were within 10% of one another and also met all other criteria. Flow-volume loop parameters were measured and reported in liters and liters per second at BTPS.

Maximal Voluntary Ventilation was measured with a Puritan Bennet Renaissance II portable spirometery system. The Renaissance spirometer was calibrated before testing began on each subject and performed in accordance with both the manufacturer's and the American Thoracic Society's guidelines. The subject was required to stand erect and wear a nose clip for each flow-volume test. They were instructed to place the spirometery mouthpiece fully into their mouths so the end of the mouthpiece was at least 1 inch beyond the exterior of their lips and to form as tight a seal as possible by keeping their mouths closed and exerting moderate force with their lips around the mouthpiece. The subject then took 3 to5 easy resting breaths before being instructed to begin breathing as deeply and quickly as possible for 12 seconds. The subjects were advised to avoid extremes of either frequency or tidal volumes since neither panting nor slow deep breathing leads to the greatest possible test values. MVV were repeated at least twice but no more than three times. Three minutes rest was given between trials to prevent fatigue that might have a negative effect upon performance. MVV results were measured and reported in liters per minute at BTPS.

Statistical Analysis

SPSS version 11.0 for Windows was used for statistical analysis. All data were reported as means and standard deviations. An alpha level of 0.05 was used to determine statistical significance. Correlational analysis was used to assess relationships of all continuous variables in the study. Analysis of variance (ANOVA) was used to determine differences in age, height, weight, BMI, and respiratory muscle force between groups. Multivariable analysis of variance (MANOVA) was used to investigate differences in forced vital capacity, forces expiratory volume one second, forced expiratory flow 25-75%, peak expiratory flow, and maximum voluntary ventilation between runners and non-runners and runners and population norms.

RESULTS

This study proposed two hypotheses. The first hypothesis was that older runners would have significantly greater ($p < 0.05$) pulmonary lung function than aged-matched nonrunners. The second hypothesis was that the runners would have significantly greater pulmonary function values than the population norms when matched for age, height, sex, and race as predicted by Knudson et al. (1983) pulmonary function prediction equations.

A subject data table (see Appendix F) and complete correlation matrix of all variables using Pearson product correlation coefficients can be found in Appendix G. There were 40 male Caucasian subjects (N = 40, 20 Runners, 20 Nonrunners). The strongest correlations were found between height and weight (0.61), weight and BMI (0.92), FVC and FEV_1 (0.79), and FEV1 and FEF_{25-75} (0.71). Moderate correlations were found between NIF and PEF (0.44), height and FVC (0.50), height and FEV_1 (0.45), height and %FVC (-0.59), weight and %FVC (-0.53), height and % FEV_1 (-0.54), weight and % FEV_1 (-0.43), MVV and FVC (0.41), MVV and FEV_1 (0.57) and MVV and PeakFlow (0.53).

ANOVA analysis of respiratory muscle strength between groups was not significant for either NIF or PEF. The NIF was 118 $\pm$ 24.2 cmH_2O for the runners and 117 $\pm$ 53.1 cmH_2O for the nonrunners with F = 0.006 and $p = 0.939$. The PEF was 144 $\pm$ 55.3 cmH_2O for the runners and 142.4 $\pm$ 56.6 cmH_2O for the nonrunners with F = 0.008 and $p = 0.931$.

Table 2 lists the mean, standard deviation (SD), F value, and the p from ANOVA analysis of the physical characteristics of age, height, weight, and BMI for runners and non-runners. The mean age for the runners was 56.0 yrs. and 52.8 yrs. for the non-runners with F = 3.252 and $p =$ 0.079 between the two groups. The mean height for the runners was 175.6 cm and 178.3 cm for the non-runners with F = 1.530 and $p = 0.224$. The mean weight for the runners was 77.5 kg and 94.1 kg for the non-runners with F = 13.640 and $p = 0.001$. The mean BMI for the runners was 25.1 and 29.5 for the non-runners with F = 16.530 and $p = 0.001$.

Table 2. ***Physical Characteristics of Subjects***

	RUNNERS		NON-RUNNERS			
	Mean	**SD**	**Mean**	**SD**	**F**	***p***
Age (yrs)	56.0	6.6	52.8	4.5	3.252	.079
Height (cm)	175.6	7.4	178.3	6.1	1.530	.224
Weight (kg)	77.5	10.6	94.1	17.1	13.640	.001*
BMI	25.1	2.4	29.5	4.2	16.530	.000*

***$p<0.05$**

A MANOVA was computed to assess differences between runners and non-runners on the absolute pulmonary function variables of forced vital capacity (FVC), forced expiratory volume one second (FEV1), forced expiratory flow 25-75% ($FEF_{25\text{-}75\%}$), peak expiratory flow (PEF), and maximum voluntary ventilation (MVV). The results of the MANOVA (*Wilk's* λ = .839, F = [1,38] = 1.306, p = .285) indicated that there was no significant difference between the two groups. The results are shown in table 3.

Table 3. MANOVA Results of Absolute Pulmonary Function Variables between Runners and Non-Runners.

	RUNNERS $N = 20$		NON-RUNNERS $N = 20$				
	MEAN	*SD*	*MEAN*	*SD*	*F*	*p*	*Eta Squared*
FVC	5.2	0.7	5.0	0.5	0.939	0.339	0.024
FEV1	3.9	0.7	3.8	0.4	0.221	0.641	0.006
FEV25-75%	3.1	1.1	3.3	0.9	0.423	0.519	0.011
PEF	9.2	1.5	8.9	1.6	0.411	0.525	0.011
MVV	159.9	23.5	144.9	20.8	4.576	0.039	0.107

***p< 0.05**

Another MANOVA was used to examine differences in pulmonary function as a percent of predicted (Knudson's 1983) between runners and nonrunners for the variables of forced vital capacity (FVC), forced expiratory volume one second (FEV1), forced expiratory flow 25-75% ($FEF_{25-75\%}$), peak expiratory flow (PEF), and maximum voluntary ventilation (MVV). The results of the MANOVA (*Wilk's* λ = .839, F = [1,38] = 2.877, p = .029) indicated a significant difference between the two groups. Three of the five measured variables returned significant differences. The runners (N = 20) had significantly greater forced vital capacity (M = 120.6, SD = 15.1 vs. M = 108.2, SD =11.5, p =. 006), significantly greater forced expiratory volume one second (M = 111.1, SD = 16.9 vs. M = 100.8, SD =8.9, p =. 022), and significantly greater maximum voluntary ventilation (M = 125.9, SD = 18.4 vs. M = 110.7, SD =14.8, p =. 007) than the non-runners (N = 20), (p = .029). Results are shown in Table 4 and bar graphs of the results can be found in appendix H.

Table 4. MANOVA Results of Predicted Pulmonary Function Variables between Runners and Non-Runners.

	RUNNERS $N = 20$		NON-RUNNERS $N = 20$				
	MEAN	*SD*	*MEAN*	*SD*	*F*	*p*	*Eta Squared*
%FVC	120.6	15.1	108.2	11.5	8.572	0.006*	0.184
%FEV1	111.1	16.9	100.8	8.9	5.694	0.022*	0.131
%FEV25-75%	87.2	26.8	83	22.9	0.284	0.597	0.007
%PEF	105.9	18.8	99.4	15.8	1.407	0.243	0.033
%MVV	125.9	18.4	110.7	14.8	8.253	0.007*	0.178

***p< 0.05**

A third MANOVA was used to examine differences in the measured pulmonary function variables of the runners compared to population norms as predicted by Knudson's (1983) prediction equations. The measured variables were (FVC), forced expiratory volume one second (FEV1), forced expiratory flow 25-75% ($FEF_{25-75\%}$), peak expiratory flow (PEF), and maximum voluntary ventilation (MVV). The runners measured absolute values were compared to their predicted values with the predicted values representing the population norms. Subjects were matched for age, height, weight, race, and sex. The results of the MANOVA (*Wilk's* λ = .304, *F* = [1,38] = 15.559, *p* = .001) indicated that there was a significant difference between the two groups. Two of the five variables were significantly different. Specifically, the runners had greater forced vital capacity (*M* = 5.19, *SD* = 0.739 vs. *M* = 4.34, *SD* = 0.674, *p* =. 001), and greater maximum voluntary ventilation (*M* = 159.9, *SD* = 23.5 vs. *M* = 125.2, *SD* = 11.0, *p* =. 001) than the general population. Results are shown in table 5.

Table 5. MANOVA Results of Predicted Pulmonary Function Variables between Runners and Population Norms.

	RUNNERS		NON-RUNNERS				
	N = 20		*N* = 20				
	MEAN	***SD***	***MEAN***	***SD***	***F***	***p***	***Eta Squared***
FVC	5.20	0.70	4.30	0.67	14.583	0.001*	0.277
FEV1	3.90	0.65	3.50	0.55	3.564	0.067	0.086
FEV25-75%	3.10	1.05	3.59	0.52	3.494	0.069	0.084
PEF	9.20	1.49	8.51	0.76	3.297	0.077	0.080
MVV	159.90	23.50	125.20	11.00	35.598	0.001*	0.484

$^*p < 0.05$

The following five figures are bar graphs that represent the difference in chronological age versus calculated lung age for runners and non-runners. The calculated lung age represents the hypothetical age of the person's lung based upon each absolute pulmonary function measurement (FVC, FEV_1, $FEF_{25\text{-}75\%}$, PEF, or MVV), height, race, and sex. The calculated lung age was derived at by using the Knudson (1983) pulmonary function prediction equation and solving for age once the measured pulmonary function value was known. Figures 1- 5 show the calculated average lung age for runners and nonrunners for FVC, FEV_1, $FEF_{25\text{-}75\%}$, PEF, and MVV.

Figure 1. Calculated Lung Age vs Chronological Age (FVC)

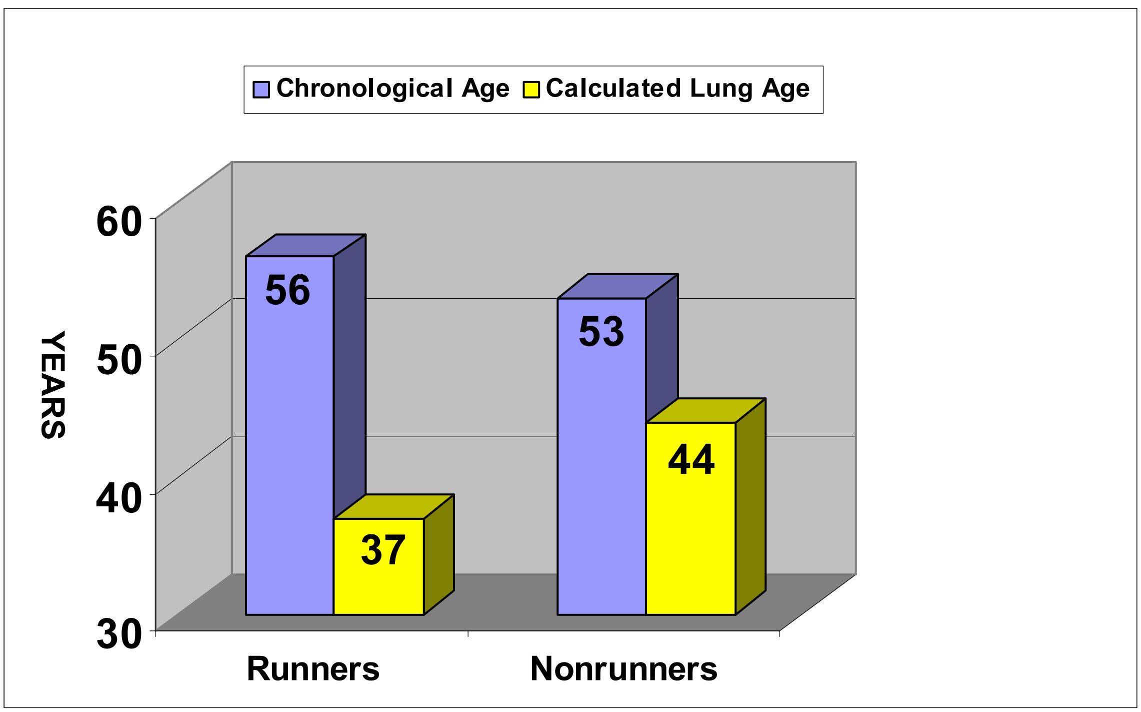


Figure 2. Calculated Lung Age vs Chronological Age (FEV1)

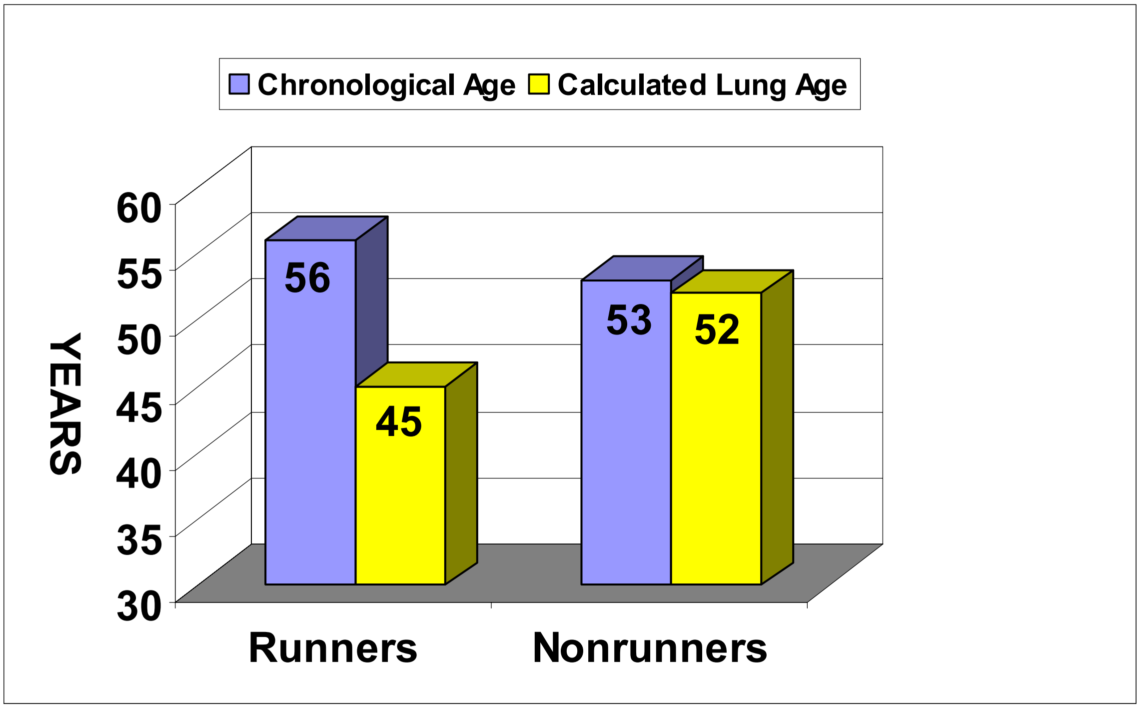


Figure 3. Calculated Lung Age vs Chronological Age ($FEF_{25\text{-}75}$)

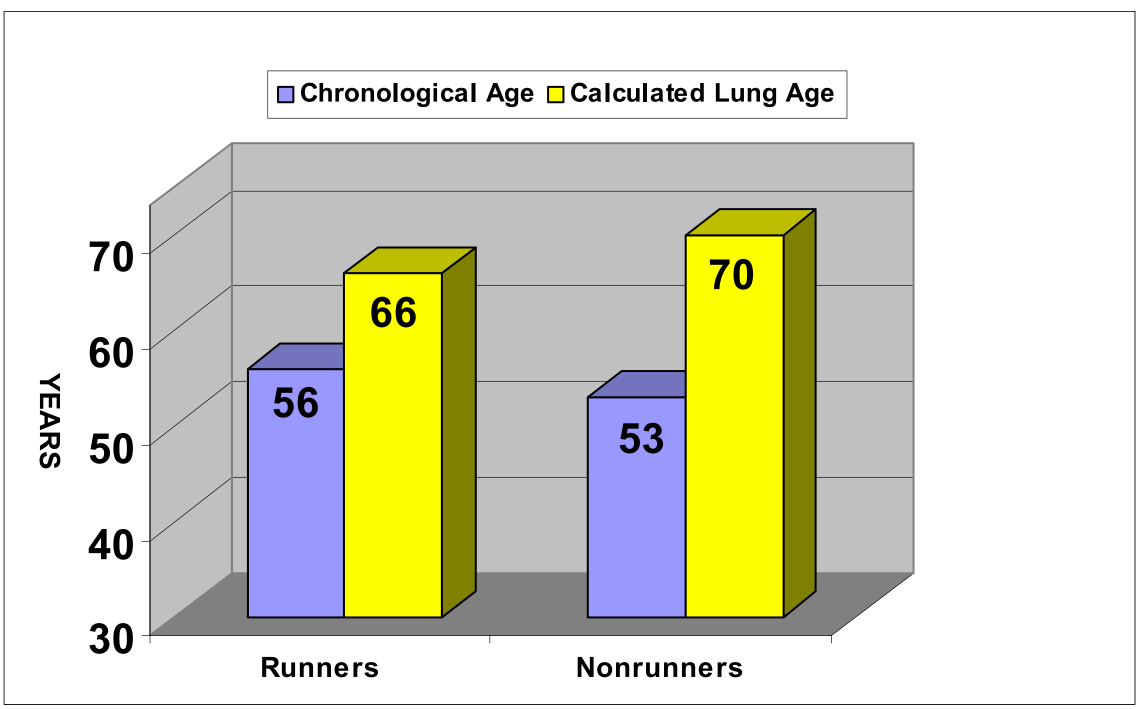


Figure 4. Calculated Lung Age vs Chronological Age (PEF)

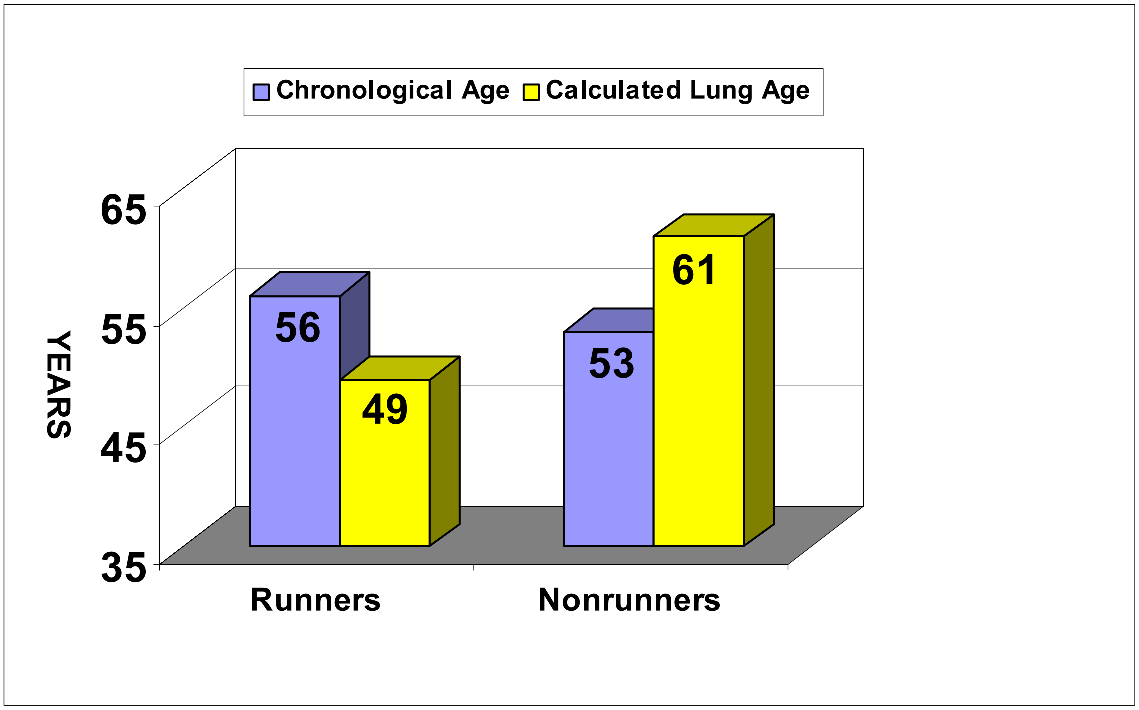
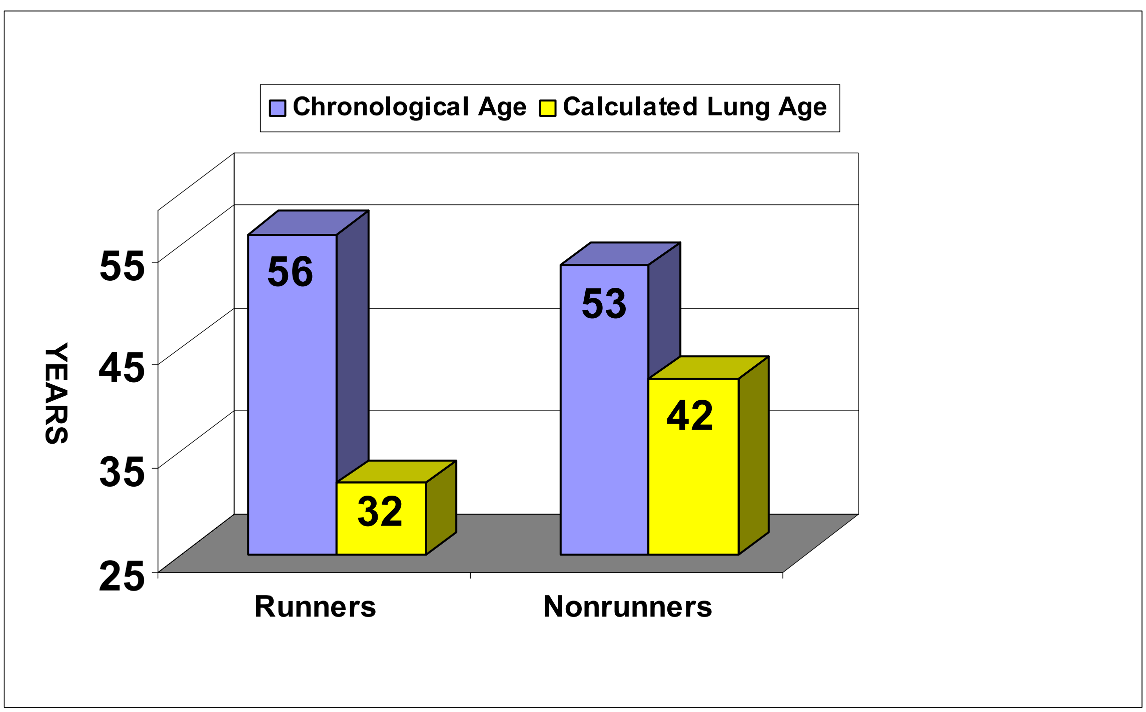


Figure 5. Calculated Lung Age vs Chronological Age (MVV)



DISCUSSION

The decline of pulmonary function associated with aging in the general population has been thoroughly investigated and repeatedly supported in the research literature. Knudson et al. (1977) conducted a study on the relationship between aging and decline in pulmonary function and concluded that there was a loss of total lung capacity related to aging. They also concluded that the declines were related to a loss of elastic recoil of the lungs. Studies by Dempsey and Seals (1995), Delorey et al. (1999), and Babb et al. (2000) all indicated similar findings relating decreases in pulmonary function to aging.

The idea that continued aerobic exercise slows the decline of pulmonary function normally associated with aging has not been researched as widely as that of the decline of pulmonary function and aging in the general population. Furthermore the existing literature presents confounding and therefore inconclusive results. For example, Hagberg et al. (1988) hypothesized from their results and the results of other studies that the improvement of pulmonary function found in older endurance athletes might be attributed to enhanced respiratory muscle function as a result of practicing aerobic exercise. The results of the current study do not support the idea that enhanced respiratory muscle function is the explanation for improved pulmonary function. The current study found significantly greater pulmonary function in the runners but no difference in respiratory muscle strength between the two groups. McClaran et al. (1995) concluded that habitual physical activity and high aerobic capacity did not modify the normal deterioration of pulmonary lung volume and function associated with aging either at rest or during exercise. The current study found pulmonary function values for the runners that compared to significantly younger individuals suggesting that habitual physical activity and high aerobic capacity might modify the normal deterioration of pulmonary lung volume and function associated with aging.

The current study examined the relationship between the pulmonary function of older male subjects (*N = 20, M* = 56.0, *SD* = 6.6) who exercised regularly by running with that of age-matched non-aerobic exercising controls (*N = 20, M* = 52.8, *SD* = 4.5). The study also examined the relationship of pulmonary function between runners and the population norms. The population norms were represented by using the predicted values of the runners as calculated by the Knudson et al. (1983) equations. Two hypotheses were proposed. The first stated that the runners would have greater pulmonary function values than the non-runners. The second hypothesis stated that the runners would have significantly greater ($p < 0.05$) pulmonary function values than the population norms when matched for age, height, sex, and race as predicted by Knudson et al. (1983) pulmonary function prediction equations. The Puritan-Bennett Renaissance II portable spirometer was used to collect pulmonary flow-volume measurements. The Technika Scientific Equipment Model 840080 manometer was used to measure maximum negative inspiratory force and positive expiratory force.

Comparison of respiratory muscle strength was assessed by measurement of maximum inspiratory and expiratory forces. Results from an ANOVA test showed no significant difference between groups ($p < 0.05$) for maximum inspiratory force. The runner's values were (*M* = 118.0, *SD* = 24.2 cmH_2O) and the non-runners values were (*M* = 117.0, *SD* = 53.2 cmH_2O). There was also no significant difference found between groups ($p < 0.05$) for maximum expiratory force. The runner's values were (*M* = 144 *SD* = 55.3 cmH_2O) and the non-runners values were (*M* = 142, *SD* = 56.6 cmH_2O). These findings were different then those of Chen et al. (1989) who found the average value for a group of 20 male subjects aged (*M* = 53.9, *SD* = 0.7) to be (*M* =

92.8, *SD* = 4.3 cmH_2O) for maximum inspiratory force and (*M* =133.6, *SD* = 9.0 cmH_2O) for maximum expiratory force. The higher values for the current study (NIF, 117 versus 93) and (PEF, 144 versus 133) may be explained by the fact that the subjects in the current study were taller (177.0 cm versus 165.1 cm) and heavier (85.9 kg versus 62.8 kg) then those tested by Chen et al. (1989). Maximum inspiratory pressure in the current study (118 $\pm$ 24 cmH_2O) also matched very closely with that of a similar study of male runners (111 $\pm$ 25 cmH_2O) (Cordain et al., 1987). A rather large difference in maximum expiratory pressure existed between the current study (144 $\pm$ 55 cmH_2O) and that of Cordain et al. (1987) (178 $\pm$ 46 cmH_2O). A possible explanation for the discrepancy may have been due to the difficulty of maintaining a tight mouth seal that prevents leaks while measuring maximum expiratory pressures. It is possible that Cordain et al., (1987) had a better mechanical arrangement for performing this test. The results of this study on respiratory muscle strength agree with the findings of Eastwood, Hillman and Finucane (2001) that concluded that respiratory muscle strength was not different between sedentary subjects and highly trained marathon runners. It would seem from the results of this study and similar studies that aerobic exercise in the form of running does not increase respiratory muscle strength when measured as either maximum inspiratory or expiratory force and therefore cannot be used to explain the greater pulmonary function of the runners.

Pulmonary function was measured using the Puritan-Bennett Renaissance II portable spirometer. Flow-volume loop spirometery was performed on all subjects and the guidelines set forth by the American Thoracic Society (1987) for pulmonary functions were followed. Forced vital capacity (FVC), forced expiratory volume one second (FEV1), forced expiratory flow 25-75% ($FEF_{25-75\%}$), peak expiratory flow (PEF), and maximum voluntary ventilation (MVV) were the measured variables. All values were recorded as both absolute and percent of predicted using the prediction equations of Knudson et al. (1983). This method was selected because Knudson's equations normalize values based upon sex, race, age, and height. Since the study sample was homogeneous for sex and race using this method presented a more elegant solution for accounting for the differences in pulmonary measurements introduced by variations in age and height. A two-way between-groups multivariate analysis of variance (MANOVA) was used to investigate differences between runners and non-runners for FVC, FEV1, $FEF_{25\text{-}75\%}$, PEF, and MVV. No significant difference was found between groups when compared as absolute measured values. Although there was not a statistically significant difference in either height nor age between the two groups, the non-runners who were slightly younger (53 vs 56 yrs) and also slightly taller (178 vs 176 cm) should have had larger absolute values according to all pulmonary function prediction equations. This was not the case; the runners had larger absolute values for all measured pulmonary function variables in spite of the fact that they were older and shorter.

When the two groups were adjusted for height and age using the Knudson prediction equations a significant difference between groups ($p < 0.05$) was found that indicated the runner's group had greater pulmonary function. The runners had greater values for FVC (120.6% versus 108.2%), FEV1 (111.1% versus 100.8%), MVV (125.9% versus 110.7%) that resulted in a MANOVA value of ($p = 0.029$). PEF was not statistically significant ($p = 0.243$) but resulted in a greater value for the runners (105.9% versus 99.4%). $FEF_{25\text{-}75\%}$ was the only pulmonary function variable that showed no appreciable difference between groups ($p = 0.597$) with average values of 87.2% for the runners and 83.0% for the non-runners.

The results of this study suggest that men aged 45-65 who have run for at least the last ten years have greater pulmonary function then age-matched non-aerobic exercising controls.

These results agree with previous research by Yerg et al. (1985), Hagberg et al. (1988), Amara et al. (2000), and Cheng, Macera, Addy, Sy, Wieland and Blair (2003).

A study on the effect of endurance training on the ventilatory function in older individuals by Yerg et al. (1985) found that prolonged endurance training in previously sedentary subjects resulted in significant positive changes. The only pulmonary function measure that this study had in common with the current study was that of MVV. The master athletes in the Yerg study had an average MVV of 163 liters per minute and the runners in the current study had an average MVV of 159 liters per minute. The sedentary subjects in Yerg's study had an average MVV of 143 liters per minute and the non-runners in the current study had an average MVV of 144 liters per minute. The Yerg study not only compared master athletes to sedentary subjects but also performed a longitudinal study that trained sedentary subjects for 12 months. Training consisted of low-intensity walking for the first six months followed by higher intensity activities such as cycling, jogging, and graded treadmill walking at 75-85% of heart rate reserve. Although a 25% increase in $VO_{2\ max}$ was achieved after training there was no increase in MVV shown after 1 year of training. There was a significant increase (p <0.005) in VE_{max} and the percent of MVV used at $VE_{max\ after}$ training. The authors concluded that prolonged endurance training in older previously sedentary individuals resulted in a significant reduction in the level of ventilation required to perform a given amount of work and this indicated an adaptation to exercise rather than an inherent characteristic of endurance athletes. The inability of the subjects in the Yerg (1985) longitudinal study to increase their MVV may have been related to the intensity and duration of the training program. They trained far less intensively and for a far shorter time then the master athletes. It is possible that had they trained longer and harder that increases in their MVV might have occurred. The authors concluded that older sedentary individuals could achieve the same efficient level of ventilation during submaximal exercise and also utilize the same percent on MVV during maximal exercise as a trained athlete.

Amara et al. (2001) reported that physical activity provided a small but significant contribution to greater FEV1 in active individuals. They also found that fat free mass (FFM) was the strongest predicator of FEV1. They indicated as the ratio of FFM to total mass (TM) increased so did the subject's FEV1's suggesting greater FEV1's for leaner individuals. Although the present study calculated BMI and not FFM it is reasonable to assume that lower BMI's should result in leaner body mass. The exception to this assumption would be if body builders were included but since they were not, the results of the current study agree with Amara et al. (2001). The average BMI of the runners in the present study was 25.1 compared to 29.5 for the non-runners with the runners having significantly greater FEV1's (111.1% versus 100.8%) then the non-runners. Amara et al. (2001) concluded that physical activity and body composition might be more important factors in determining forced expiratory function than previously recognized.

Hagberg et al. (1988) found that a group of older athletes had 119 $\pm$ 18% of their predicted vital capacity compared to 99 $\pm$ 10% predicted for older sedentary subjects. These values compared favorably with the results from the current study, especially for the runners who had vital capacities of 121 $\pm$ 15% while the non-runners measured at 108 $\pm$ 12% of predicted. The FEV_1 for the older athletes in Hagberg's study had 123 $\pm$ 15% predicted versus 107 $\pm$ 15% predicted for the sedentary controls. This compared to 111 $\pm$ 17% predicted for the older runners and 101 $\pm$ 9% predicted for the non-runners in the current study. Although the FEV_1 values from the two studies are not as close as those for vital capacity they both show a significant difference with the athletes/runners having greater pulmonary function measures then the non-athletes.

Maximum voluntary ventilation (MVV) was also tested in both studies with similar results. The older athletes in the Hagberg study had values of 119 ± 18% that compared to 125 ± 18% for runners in the current study. The older non-athletes in the Hagberg study had values of 108 ± 17% compared to 111 ± 15% for the non-runners in the current study. The Hagberg study included not only older athletes and sedentary controls but also young athletes and sedentaries. They found no difference when they compared the pulmonary function of the young athletes with that of the young untrained men. They did find a significant difference between the pulmonary function of the older athletes and the older sedentaries. They also found the older athletes were the only group that had lung volumes and pulmonary function values that were substantially greater than predicted. Hagberg et al. (1988) concluded that the older athletes appeared to have slowed or lessened the age-related decline of pulmonary function normally found in the general population through the practice of continued strenuous endurance exercise. The results of the current study agree with the findings made by Hagberg et al. and further support the idea that aerobic exercise is related to greater than predicted pulmonary function in older men.

The results of the current study were also in agreement with the findings of Cheng et al. (2003). This was a large study that was both cross-sectional and longitudinal in design. The cross sectional portion included 24,536 healthy subjects and the longitudinal study lasted five years and included 5,707 subjects. The purpose of this dual design study was to compare the role of respiratory function on the association of change in physical activity habits and also the changes that occur over time in healthy individuals. The cross-sectional study results indicated that the men in the highest activity group had average FVC values of 5.14 liters compared to 4.87 for the sedentary group and average FEV1 values of 4.02 liters compared to 3.79 liters for the sedentary. The average FVC in the current study was 5.19 liters for the runners and 4.99 liters for the non-runners and the average FEV1 was 3.86 liters for the runners and 3.78 liters for the non-runners. The activity levels were very similar in both studies. Cheng defined high activity as running at least 20 miles per week and the average of the runners in the current study was 24 miles per week.

The longitudinal results of the Cheng et al. showed that men who remained active over the five-year study period were the only group that improved or maintained their FVC and FEV1 values. Cheng et al. (2003) concluded that physical activity was important in maintaining both cardiovascular and respiratory function.

A seven-year longitudinal study by McClaran et al. (1995) found no evidence that physical activity slowed the decline of pulmonary function associated with aging in active older subjects. Average group vital capacity declined from 4.16 liters to 3.72 liters and FEV1 declined from 3.18 liters to 2.78 liters over a seven-year period. McClaran et al. (1995) concluded that habitual physical activity and aerobic exercise did not modify the normal deterioration of pulmonary function associated with aging. A possible reason for the discrepancy in findings between this study and others such as Hagberg et al. (1988) may be explained by the fact that the subjects in the McClaran study were older with an average age of 72.9 years and a range from 62 to 82. The average age of the runners in the current study was 56.0 years with a range from 46 to 65. The average age of the older athletes in the Hagberg study was 65 and the average age of the male subjects in the Cheng study was 40.9 years with a range from 25 to 55. If conclusions of McClaran et al. (1995) are correct then it is possible that the protective benefits of aerobic exercise on pulmonary function becomes less effective with age. It is also possible that other factors associated with aging, such as muscular, skeletal, joint, and or cardiac problems might prevent the older subjects from exercising at a sufficient intensity to maintain the benefits to pulmonary function seen in the younger subjects.

The calculated lung age versus chronological calculations and bar graphs combined the results of the runners and non-runners and that of the runners and population norms into one picture. Each figure with the exception of $FEF_{25\text{-}75}$ clearly showed that the runners had greater pulmonary function values than both the non-runners and the population norms.

CONCLUSION

The findings from the current study supported both proposed hypotheses. The results supported the hypothesis that older runners would have greater pulmonary function than older non-runners. A significant difference ($p < 0.05$) for pulmonary function was found between older runners and older non-runners. The non-runners were screened to exclude for any types of aerobic exercise other than casual walking. Activity level, either runner or non-runner, was the independent variable and forced vital capacity (FVC), forced expiratory volume one second (FEV1), forced expiratory mid flow ($FEF_{25\text{-}75\%}$), peak expiratory flow (PEF), and maximum voluntary ventilation (MVV) were the measured dependent variables. Multivariate analysis resulted in a significant difference ($p < 0.05$ with the runners having greater pulmonary function values than the non-runners. Univariate analysis resulted in significant differences for three of the five independent variables, FVC, FEV1, and MVV with PEF approaching significance. $FEF_{25\text{-}75\%}$ was the only variable that showed no significant difference between groups. The fact that $FEF_{25\text{-}75\%}$ was not significantly different between the two groups was not that surprising a finding when effort independent nature of a $FEF25_{\text{-}75\%}$ is considered. Age and height differences were controlled for using the Knudson et al. (1983) pulmonary prediction equations. Subjects were then compared based upon their scores as a percent of predicted. The results of the current study were in close agreement with the results of several similar or related studies.

In addition to using percent of predicted scores for multivariate analysis calculated lung age versus chronological age was also compared. The Knudson prediction equations for FVC, FEV_1, $FEF_{25\text{-}75\%}$, PEF and MVV were used to solve for age once the subject's actual pulmonary function value was known. The runners calculated lung age was lower than the non-runners in every category even though the non-runners were chronologically three years younger than the runners. The runners had younger predicted lung ages for FVC (*M* = 37 vs. *M* = 44), FEV_1 (*M* = 45 vs. *M* = 52), $FEF_{25-75\%}$, (*M* = 66 vs. *M* = 70), PEF (*M* = 49 vs. *M* = 61), and MVV (*M* = 32 vs. *M* = 42) than the non-runners. The older runners calculated lung ages were well below their actual chronological ages in every category except for $FEF_{25-75\%.}$ Both groups, runners and non-runners, had calculated lung age scores greater than their actual chronological ages for $FEF_{25-75\%}$. $FEF_{25-75\%}$ is the one of the best indicators of reduced pulmonary function of small airways seen in asthma and reactive type airway diseases. A possible explanation for this finding may be the local environment and air quality. Southern Louisiana has a large petro-chemical industry contributing to poor air quality combined with air that normally has a high pollen and mold count, both factors are know contributors to respiratory diseases. The nature of this question was beyond the scope of the present study and only offers a purely speculative explanation.

Respiratory muscle strength was measured as maximum inspiratory and expiratory force generation. There was essentially no difference between the runners and non-runners for either measure. Respiratory muscle strength was not considered a measure of pulmonary function but as a potential explanation for differences between groups. No significant differences were found therefore the author could not conclude that respiratory muscle strength was related to pulmonary function.

The second hypothesis stated that the older runners would have greater pulmonary function than the general population as predicted by the Knudson et al. (1983) pulmonary function prediction equations. The results supported the hypothesis that older runners would have greater pulmonary function than the general population. A significant difference ($p < 0.05$) for pulmonary function was found between older runners and the general population. Multivariate analysis resulted in a significant difference ($p < 0.05$) with the runners having greater pulmonary function values than the general population. Univariate analysis resulted in significant differences for two of the five independent variables. The runners had significantly greater values for FVC and MVV than the general population with FEV_1 and PEF approaching significance. The $FEF_{25\text{-}75\%}$ also approached significance however this value was greater for the general population then for the older runners.

In summary, the findings of greater pulmonary function values for the older athletes compared to the controls in the current study are generally similar to those found in studies by Yerg et al. (1985), Hagberg et al. (1988), and Amara et al. (2001). The results suggest that high levels of physical activity, such as endurance running, may lead to a slower decline in pulmonary function then typically seen in the sedentary population. The findings of greater pulmonary function values for the older athletes when compared to the general population would also suggest that physical activity might positively enhance pulmonary functions in this age group.

Opportunities for future study would be to follow the same subjects over time. A longitudinal study would yield insightful information on whether or not long-term aerobic exercise does in fact slow the decline of pulmonary function that is observed in the normal population. Another question raised by this study was why did both the runners and non-runners have $FEF_{25\text{-}75}$ values that were below the population norms?

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APPENDIX A

UNIVERSITY OF NEW ORLEANS
COMMITTEE ON THE USE OF HUMAN SUBJECTS

Form Number: 9APR04 ***(please refer to this number in all future correspondence concerning th protocol)***

Principal Investigator: James Buras **Title:** Graduate student

Department: HPHP **College:** Education & Human Development

Name of Faculty Supervisor: Mark Loftin ***(if PI is a student)***

Project Title: Does endurance running slow the rate of deterioration of pulmonary functions norma associated with aging?

Date Reviewed: March 17, 2004

Dates of Proposed Project Period: From 4/04 to 4/05
***approval is for one year from approval date only and may be renewed yearly.**

Note: Consent forms and related materials are to be kept by the PI for a period of three years following the completion of the study.

☐ **Full Committee Approval**
☒ **Expedited Approval**
☐ **Continuation**
☐ **Rejected**
☐ **The protocol will be approved following receipt of satisfactory response(s) to the following question(s) within 15 days:**

____
____
____

Committee Signatures:

______________________ Scott C. Bauer, Ph.D. (Chair)
______________________ Anthony Kontos, Ph.D.
______________________ Betty Lo, M.D.
______________________ Jayaraman Rao, M.D. (NBDL protocols only)
______________________ Laura Scaramella, Ph.D.
______________________ Richard B. Speaker, Ph.D.
______________________ Gary Talarchek, Ph.D.

APPENDIX B

Participant Consent Form

1. **Title of Research Study:** Comparison of the pulmonary function of older endurance athletes with age-matched sedentary controls.

2. **Research Director:** James C. Buras, Graduate Student, 504-488-9366, jcburas@uno.edu

3. **Purpose of Research:** The purpose of this research will be to determine if endurance running has a positive effect upon the decline of pulmonary function normally associated with aging.

4. **Procedures for this Research:** For this study you will be asked to first complete a questionnaire regarding your exercise habits and then have your lung function measured. Lung function measurement will involve three different tests. The first will measure maximum inspiratory and expiratory force. This test requires inhaling and exhaling as hard as possible. The second test employs spirometery to measure lung volumes and flows and involves inhaling to your maximum lung capacity and then exhaling forcefully and completely. You will be asked to repeat this test several times. The third test measures maximum minute ventilation and involves breathing as deeply and quickly as possible for 12 seconds. The entire test procedure should not take more than 15 to 20 minutes.

5. **Potential Risk of Discomfort:** The potential risks of discomfort are minimal. Fatigue, shortness of breath, and or lightheadedness are possible but unlikely complications associated with pulmonary function tests. You will be given as much break time as needed between tests to rest before testing resumes. If you wish to discuss these or any other discomforts that you may experience, you may call the Project Director listed in #2 of this form.

6. **Potential Benefits to You or Others:** You will be given a copy of your pulmonary function tests with values compared to population norms. The information from this study will help us to better understand the relationship between aerobic exercise and aging. Additionally, upon your request, you may receive a summary of the group data from this study from the Project Director.

7. **Alternative Procedures:** There are no alternative procedures associated with this study. Your participation in this study is entirely voluntary and you may withdraw consent and terminate participation at anytime without consequence.

I have been fully informed of the above-described procedure with its possible benefits and risks and I have given permission of participation in this study.

____________________	____________________	
Signature of Participant	Name of participant (Print)	Date ____________
____________________	____________________	
Signature of Person Obtaining Consent	Name of Person Obtaining Consent (Print)	Date ____________

APPENDIX C

Subject Questionnaire

Jim Buras 504-488-9366/jcburas@uno.edu

My name is Jim Buras and I'm a graduate student at UNO. My master's thesis involves examining the relationship between distance-running and pulmonary lung function. The tests involved in this study will require approximately 15 to 20 minutes of your time and involve only a minimal amount of physical exertion or discomfort. Your participation will be greatly appreciated.

NAME ___________________________________

Telephone # ________________________ Email ______________________

AGE ___________ HEIGHT __________ WEIGHT __________

1. Do you consider yourself to be in relatively good health? YES NO (circle one)

2. Do you have any heart or lung diseases? YES NO (circle one)

3. Do you currently smoke cigarettes? YES NO (circle one)

4. If you previously smoked how ago did you stop? _______

5. Do you participate in any kind of regular exercise routine? YES NO (circle one)

6. Are you a runner? YES NO (circle one) If NO skip to line 12.

7. If yes what is your average miles per week during last 12 months? _________

8. How many years have you been running? ____________

9. At what age did you start running? ___________

10. How many marathons have you run? ____ Date of last marathon________ PR ______

11. Date of last 10K _______Time for last 10K ________ 10K PR ______ 5K PR ______

12. Describe your exercise routine if any in detail. (Example: walk 2 miles 3 times a week)

____

____

APPENDIX D

SPIROMETER CALIBRATION PROCEDURE

Standard calibration verification of the Puritan-Bennett Renaissance II spirometer will be performed before testing of each subject in order to verify the accuracy of the system. The ATS recommends a calibration check be performed on a daily basis however calibration will be performed before each and every subject to further insure accuracy and reliability of results. A standard 3-liter calibration syringe model #P-000300-000 manufactured by the Puritan-Bennett Corporation will be used. The following procedure will be used to calibrate the spirometer.

1. The FSII flow sensor will be connected to the spirometer via the pressure tubing.
2. The Renaissance II spirometer will be turned on.
3. When the "CAL NOW" screen appears "YES" will be pressed.
4. The numeric code on the flow sensor will be entered.
5. Verification or correction of the barometric will be made.
6. The calibration syringe will be connected to the spirometer.
7. Begin with the plunger of the calibration syringe fully extended, press the "PROCEED" key, and push the plunger in slowly and smoothly over a time period of approximately one to two seconds.
8. The "DONE" key will be pressed.
9. Pull the plunger fully out to the fully extended position again and repeat steps 7 and 8 to perform an "INSPIRATORY CAL"
10. If the calibration was successful the syringe volume, measured volume, and error percent will be displayed on the final screen.
11. If the calibration was not successful repeat steps 7 through 9.
12. Once a successful calibration is attained press "DONE" to save the calibration check and then "PRINT" to print out a record of the results.

APPENDIX E

Sample Spirometery Report

Spirometry Report
Puritan-Bennett Renaissance II
S/N: G040700181
Version: 1.1.11

Session Date: 31JUL2004
Session Time: 01:21PM
Last Cal Check: 31JUL2004

BEST 3 FVC/FVL REPORT

	09261952	Height: 67"	Physician:	Sensor Code:	043155
:	LEGEND	Age: 51YRS	Technician:	Temperature:	72F
Gender:	MALE	Weight: 150LBS		Barometric Press:	760mmHg
Medication:		Smoker: NO		BTPS Correction:	1.104
Dosage:		Ethnicity/Correction: CAUCASIAN	100.0%	Normals:	KNUDSON 83

Clinical Format: PREMED - 01:23PM
Best Criteria: VAL

* Indicates Best Value

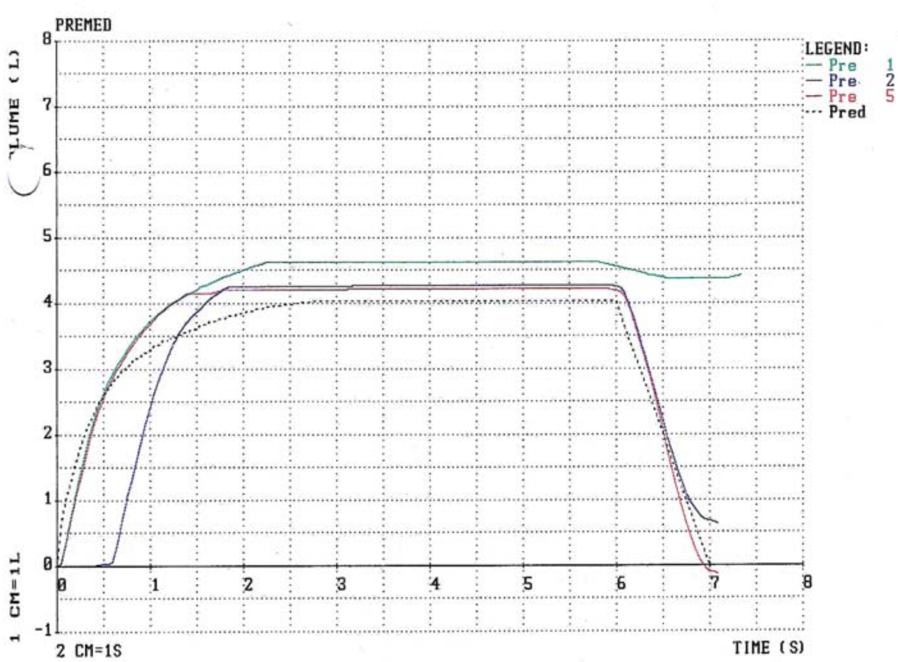
< Indicates Below LLN

MEASUREMENT	Trial 1	%Pred	Trial 2	Trial 5	Pred	LLN
FVC (L)	4.63*	114	4.31	4.22	4.05	2.97
FEV1 (L)	3.81	115	4.03*	3.77	3.30	2.55
FEV1%	82	100	93	89	82	71
FEF25-75 (L/S)	3.68*	105	4.90	4.22	3.47	
PEF(L/S)	7.62*	92	7.28	7.05	8.20	
FET (S)	2.42*		1.46	1.77		
FIVC (L)	0.26*	6	3.65	4.37	4.05	
PIF(L/S)	0.47*		5.25	6.13		
FEF50/FIF50	10.52*		1.12	0.83		

BEST FEV1% 87*

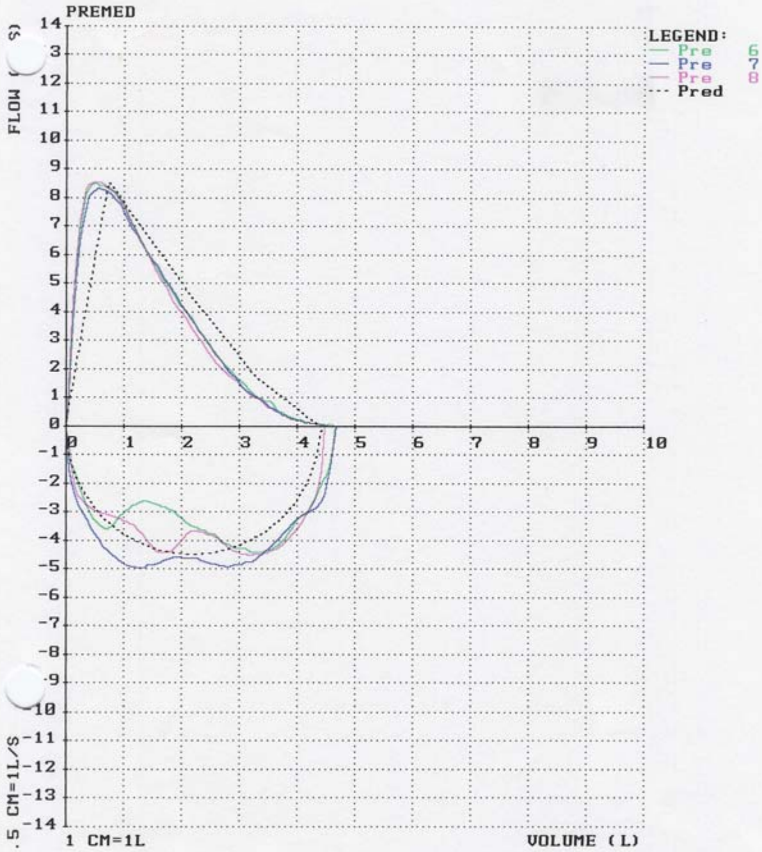
Report Summary:
Pre Med: Tests 5 Acceptable 0 Reproducible 0 FVC VAR: 320ML FEV1 VAR: 224ML PEF VAR: 344ML/S

ATS Interpretation: PREMED - Normal Spirometry
Comment:



Spirometry Report
Puritan-Bennett Renaissance II
S/N: G040700181

Session Date: 07JUL2004
Session Time: 06:16PM
Last Cal Check: 08JUL2004



Page 2 of 4

Spirometry Report
Puritan-Bennett Renaissance II
S/N: G040700181
Version: 1.1.11

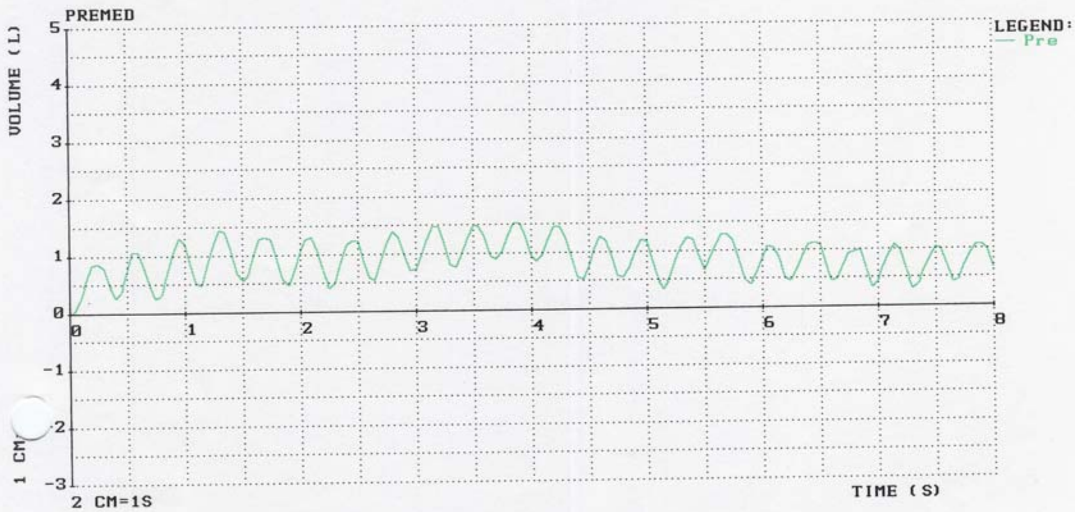
Session Date: 07JUL2004
Session Time: 06:16PM
Last Cal Check: 08JUL2004

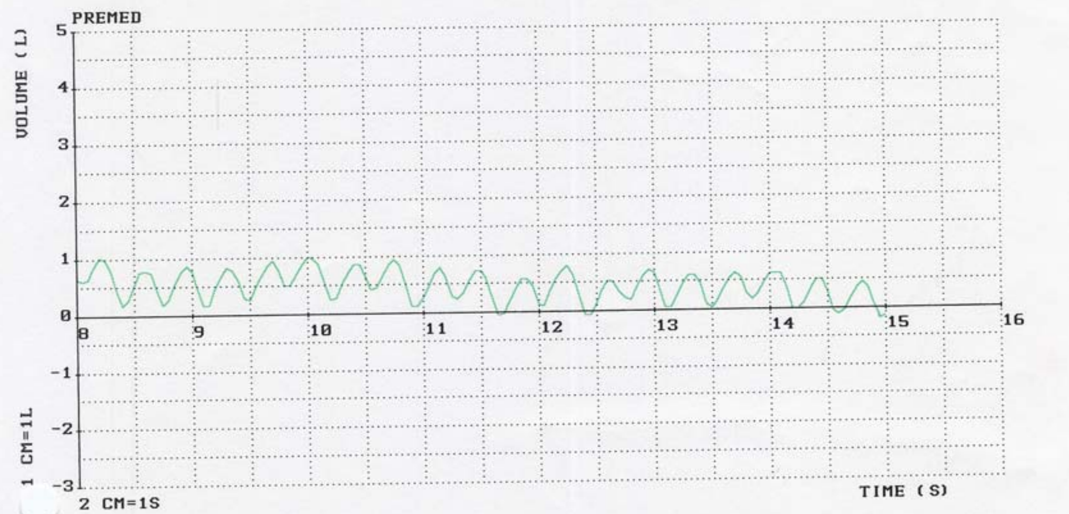
BEST MVV REPORT

ID:	09101950	Height:	69"	Physician:			Sensor Code:	455293
:	BRINKMAN	Age:	53YRS	Technician:			Temperature:	72F
Gender:	MALE	Weight:	150LBS				Barometric Press:	760mmHg
Medication:		Smoker:	NO				BTPS Correction:	1.104
Dosage:		Ethnicity/Correction:		CAUCASIAN		100.0%	Normals:	KNUDSON 83

Clinical Format: PREMED - 06:28PM

MEASUREMENT	Trial 1	%Pred	Pred
MVV (L/M)	136.6	106	127.8
RR (BPM)	168		





APPENDIX F

SUBJECT DATA TABLE KEY

A – Subject (1 = Runners, 2 = Non-runners)

B – Age (years)

C – Height (inches)

D – Weight (pounds)

E – Body Mass Index

F – Negative Inspiratory Force (cmH_2O)

G – Positive Expiratory Force (cmH_2O)

H – Actual Forced Vital Capacity (liters)

I – Actual Forced Expiratory Volume One Second (liters)

J – Actual Forced Expiratory Flow$_{25\text{-}75\%}$ (liters per second)

K – Actual Peak Expiratory Flow (liters per second)

L– Actual Maximum Voluntary Ventilation (liters per minute)

M – Relative Forced Vital Capacity (liters)

N – Relative Forced Expiratory Volume One Second (liters)

O – Relative Forced Expiratory Flow$_{25\text{-}75\%}$ (liters per second)

P – Relative Peak Expiratory Flow (liters per second)

Q – Relative Maximum Voluntary Ventilation (liters per minute)

R – Percent Predicted Forced Vital Capacity

S – Percent Predicted Forced Expiratory Volume One Second

T – Percent Predicted Forced Expiratory Flow$_{25\text{-}75\%}$

U – Percent Predicted Peak Expiratory Flow

V – Percent Predicted Maximum Voluntary Ventilation

SUBJECT DATA TABLE

Sub	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	1	46	70	168	24.2	139	199	6.29	5.30	4.43	13.03	210	3.54	2.98	2.49	7.33	118	129	133	107	142	153
2	1	46	72	175	23.8	140	95	5.08	4.30	4.31	11.49	197	2.78	2.35	2.36	6.28	108	96	99	97	119	138
3	1	47	72	170	23.1	142	203	6.57	5.16	4.76	8.80	172	3.59	2.82	2.60	4.81	94	124	120	108	92	121
4	1	49	71	163	22.8	112	250	6.35	4.33	3.02	8.75	179	3.52	2.40	1.67	4.85	99	132	111	75	96	133
5	1	49	72	193	26.2	75	94	5.76	3.21	2.16	8.93	112	3.15	1.76	1.18	4.88	61	116	79	69	61	81
6	1	50	69	190	28.1	128	154	4.68	3.37	2.29	8.59	137	2.67	1.92	1.31	4.90	78	106	94	62	99	106
7	1	51	64	148	25.5	101	77	4.20	3.04	2.02	9.41	162	2.58	1.87	1.24	5.79	100	121	107	65	124	141
8	1	53	69	145	21.5	110	64	4.68	3.37	2.29	8.59	137	2.88	2.07	1.41	5.28	78	106	94	62	99	106
9	1	55	69	155	22.9	145	183	5.31	3.46	2.09	7.78	152	3.03	1.97	1.19	4.44	87	122	98	57	91	120
10	1	58	67	172	27	140	184	4.56	3.38	2.35	10.68	174	2.68	1.99	1.38	6.28	102	125	115	76	138	118
11	1	58	67	160	25.1	140	117	5.30	4.15	3.68	9.41	154	3.11	2.44	2.16	5.53	91	138	133	114	118	131
12	1	58	69	190	28.1	103	116	5.17	3.80	2.64	9.73	184	2.95	2.17	1.51	5.55	105	114	104	71	111	144
13	1	59	73	203	26.8	139	141	5.70	4.55	4.26	10.73	161	3.07	2.45	2.30	5.79	87	112	111	105	115	119
14	1	61	63	152	27	132	181	4.46	3.12	1.84	8.23	169	2.79	1.95	1.15	5.14	106	153	133	73	119	164
15	1	61	69	170	25.3	108	99	5.09	3.65	2.57	8.34	159	2.90	2.08	1.47	4.76	91	122	109	75	100	130
16	1	62	65	135	22.5	111	208	4.71	3.82	3.86	6.86	146	2.85	2.31	2.34	4.16	88	142	144	138	93	134
17	1	62	70	179	25.7	136	88	4.34	3.79	5.17	9.32	137	2.44	2.13	2.91	5.24	77	98	107	146	108	110
18	1	64	67	145	22.8	106	198	4.52	3.60	3.28	7.01	128	2.66	2.12	1.93	4.12	75	123	123	109	90	113
19	1	65	72	165	22.4	58	67	6.30	4.53	3.06	10.20	167	3.44	2.48	1.67	5.58	91	133	120	82	114	130
20	1	65	73	234	30.9	95	160	4.73	3.31	1.97	8.00	160	2.55	1.79	1.06	4.31	86	100	87	52	89	126
21	2	45	68	190	28.9	82	127	4.70	3.71	3.51	7.78	136	2.72	2.15	2.03	4.50	79	105	100	90	89	103
22	2	45	76	310	37.8	300	235	6.07	4.68	4.16	9.56	169	3.14	2.42	2.15	4.95	88	98	93	82	90	109
23	2	49	67	155	24.3	61	65	4.44	3.20	2.18	8.09	131	2.61	1.88	1.28	4.75	77	108	95	61	97	104
24	2	49	69	170	25.2	80	76	4.84	4.11	4.94	11.00	162	2.76	2.35	2.82	6.28	92	106	111	128	125	123
25	2	49	73	190	25.1	146	207	5.74	4.03	2.63	9.80	139	3.10	2.17	1.42	5.29	75	106	92	59	101	97
26	2	50	69	200	29.6	126	200	5.78	4.43	3.90	7.53	167	3.30	2.53	2.23	4.30	95	128	120	102	86	128
27	2	50	70	210	30.2	123	154	4.96	3.89	3.76	7.65	159	2.79	2.19	2.11	4.30	89	104	101	95	85	119
28	2	52	73	285	37.7	99	66	4.77	4.12	5.55	10.13	144	2.57	2.22	2.99	5.46	78	93	99	132	107	104
29	2	53	67	195	30.6	75	67	5.31	3.58	2.92	8.13	107	3.12	2.10	1.72	4.78	63	133	110	50	99	87
30	2	53	69	216	32	126	141	4.73	3.59	3.03	6.35	123	2.70	2.05	1.73	3.62	70	107	101	82	74	95
31	2	53	70	240	34.5	80	93	4.89	3.95	4.28	6.43	136	2.75	2.22	2.41	3.62	77	104	104	110	72	102
32	2	53	71	190	26.6	104	186	4.37	2.91	1.79	7.07	124	2.42	1.61	0.99	3.92	69	112	92	53	104	111
33	2	53	73	184	24.3	117	142	5.55	4.10	2.99	11.46	159	2.99	2.21	1.61	6.18	86	105	96	69	120	113
34	2	54	68	160	24.4	116	146	4.51	3.35	2.48	9.12	144	2.61	1.94	1.44	5.28	83	107	98	69	108	116
35	2	55	70	225	32.4	114	248	5.36	3.78	2.60	8.91	167	3.01	2.13	1.46	5.01	94	116	101	68	101	129
36	2	56	69	208	30.8	203	98	4.69	3.81	3.97	11.07	181	2.68	2.17	2.27	6.32	103	108	109	100	130	144
37	2	56	70	200	28.8	103	181	4.22	3.33	3.15	9.99	105	2.37	1.87	1.77	5.62	59	92	90	83	113	82
38	2	57	69	225	33.3	73	116	4.89	3.64	2.91	7.20	151	2.79	2.08	1.66	4.11	86	114	105	82	85	121
39	2	61	69	189	28	102	112	5.35	3.84	2.67	9.86	135	3.05	2.19	1.52	5.63	77	128	115	78	92	111
40	2	62	74	200	25.7	110	187	4.74	3.56	2.73	10.50	158	2.52	1.89	1.45	5.59	84	90	85	66	110	116

APPENDIX G

Correlation Matrix

		SUBJECT	AGE	HEIGHT	WEIGHT	BMI	NIF	PEForce
SUBJECT	Pearson Correl	1.00	-0.28	0.20	0.51	0.55	-0.01	-0.01
N = 40	Sig. (2-tailed)	.	0.08	0.22	0.00	0.00	0.94	0.93
AGE	Pearson Correl	-0.28	1.00	-0.19	-0.19	-0.13	-0.22	-0.06
N = 40	Sig. (2-tailed)	0.08	.	0.24	0.25	0.41	0.18	0.70
HEIGHT	Pearson Correl	0.20	-0.19	1.00	0.61	0.24	0.29	0.16
N = 40	Sig. (2-tailed)	0.22	0.24	.	0.00	0.13	0.07	0.31
WEIGHT	Pearson Correl	0.51	-0.19	0.61	1.00	0.92	0.34	0.07
N = 40	Sig. (2-tailed)	0.00	0.25	0.00	.	0.00	0.03	0.68
BMI	Pearson Correl	0.55	-0.13	0.24	0.92	1.00	0.23	-0.02
N = 40	Sig. (2-tailed)	0.00	0.41	0.13	0.00	.	0.15	0.92
NIF	Pearson Correl	-0.01	-0.22	0.29	0.34	0.23	1.00	0.44
N = 40	Sig. (2-tailed)	0.94	0.18	0.07	0.03	0.15	.	0.00
PEForce	Pearson Correl	-0.01	-0.06	0.16	0.07	-0.02	0.44	1.00
N = 40	Sig. (2-tailed)	0.93	0.70	0.31	0.68	0.92	0.00	.
ACT FVC	Pearson Correl	-0.16	-0.29	0.50	0.12	-0.10	0.23	0.30
N = 40	Sig. (2-tailed)	0.34	0.07	0.00	0.48	0.53	0.15	0.06
ACT FEV1	Pearson Correl	-0.08	-0.29	0.45	0.19	0.00	0.35	0.21
N = 40	Sig. (2-tailed)	0.64	0.07	0.00	0.25	1.00	0.03	0.18
ACT FEF_{25-75}	Pearson Correl	0.10	-0.23	0.29	0.31	0.23	0.25	-0.10
N = 40	Sig. (2-tailed)	0.52	0.16	0.07	0.05	0.16	0.13	0.55
ACT PEFlow	Pearson Correl	-0.10	-0.12	0.33	-0.01	-0.18	0.26	-0.09
N = 40	Sig. (2-tailed)	0.53	0.45	0.04	0.96	0.28	0.11	0.57
ACT MVV	Pearson Correl	-0.33	-0.10	0.12	-0.04	-0.12	0.38	0.24
N = 40	Sig. (2-tailed)	0.04	0.54	0.45	0.80	0.46	0.02	0.14
REL FVC	Pearson Correl	-0.26	-0.26	0.21	-0.10	-0.22	0.15	0.26
N = 40	Sig. (2-tailed)	0.11	0.11	0.19	0.54	0.17	0.36	0.11
REL FEV1	Pearson Correl	-0.16	-0.26	0.20	0.01	-0.09	0.28	0.17
N = 40	Sig. (2-tailed)	0.34	0.11	0.22	0.96	0.56	0.08	0.30
REL FEF_{25-75}	Pearson Correl	0.08	-0.20	0.18	0.23	0.19	0.21	-0.13
N = 40	Sig. (2-tailed)	0.62	0.21	0.28	0.15	0.25	0.20	0.44
REL PEFlow	Pearson Correl	-0.17	-0.09	0.10	-0.17	-0.26	0.20	-0.16
N = 40	Sig. (2-tailed)	0.29	0.58	0.53	0.30	0.11	0.22	0.34
REL MVV	Pearson Correl	-0.38	-0.05	-0.14	-0.20	-0.18	0.30	0.19
N = 40	Sig. (2-tailed)	0.02	0.78	0.38	0.22	0.27	0.06	0.23
% FVC	Pearson Correl	-0.43	0.24	-0.59	-0.53	-0.36	-0.11	0.18
N = 40	Sig. (2-tailed)	0.01	0.13	0.00	0.00	0.02	0.50	0.27
% FEV1	Pearson Correl	-0.36	0.26	-0.54	-0.43	-0.27	0.04	0.13
N = 40	Sig. (2-tailed)	0.02	0.11	0.00	0.01	0.09	0.82	0.41
% FEF_{25-75}	Pearson Correl	-0.09	0.04	-0.03	0.04	0.06	0.11	-0.09
N = 40	Sig. (2-tailed)	0.60	0.79	0.84	0.79	0.73	0.50	0.58
% PEFlow	Pearson Correl	-0.19	0.09	-0.15	-0.28	-0.28	0.18	-0.06
N = 40	Sig. (2-tailed)	0.24	0.57	0.36	0.08	0.08	0.27	0.72
% MVV	Pearson Correl	-0.42	0.20	-0.30	-0.30	-0.23	0.19	0.17
N = 40	Sig. (2-tailed)	0.01	0.22	0.06	0.06	0.15	0.23	0.30
MILS WK	Pearson Correl	.	-0.06	-0.10	-0.36	-0.42	-0.21	0.03
N = 20	Sig. (2-tailed)	.	0.81	0.68	0.12	0.06	0.37	0.90
YRS RUN	Pearson Correl	.	0.41	-0.12	0.21	0.34	-0.13	-0.16
N = 20	Sig. (2-tailed)	.	0.07	0.63	0.38	0.14	0.60	0.50
MARATH	Pearson Correl	.	-0.13	0.21	-0.21	-0.45	-0.30	0.22
N = 20	Sig. (2-tailed)	.	0.58	0.38	0.37	0.05	0.20	0.35
10K PR	Pearson Correl	.	0.16	0.16	0.58	0.66	-0.08	0.05
N = 20	Sig. (2-tailed)	.	0.50	0.50	0.01	0.00	0.73	0.84
5K PR	Pearson Correl	.	0.15	0.19	0.52	0.57	-0.09	0.01
N = 20	Sig. (2-tailed)	.	0.53	0.43	0.02	0.01	0.71	0.95
Correlation is significant at the 0.01 level (2-tailed).								
Correlation is significant at the 0.05 level (2-tailed).								

Correlation Matrix

		ACTUAL FVC	ACTUAL FEV1	ACTUAL FEF_{25-75}	ACTUAL PEFlow	ACTUAL MVV
SUBJECT	Pearson Correlation	-0.16	-0.08	0.10	-0.10	-0.33
N = 40	Sig. (2-tailed)	0.34	0.64	0.52	0.53	0.04
AGE	Pearson Correlation	-0.29	-0.29	-0.23	-0.12	-0.10
N = 40	Sig. (2-tailed)	0.07	0.07	0.16	0.45	0.54
HEIGHT	Pearson Correlation	0.50	0.45	0.29	0.33	0.12
N = 40	Sig. (2-tailed)	0.00	0.00	0.07	0.04	0.45
WEIGHT	Pearson Correlation	0.12	0.19	0.31	-0.01	-0.04
N = 40	Sig. (2-tailed)	0.48	0.25	0.05	0.96	0.80
BMI	Pearson Correlation	-0.10	0.00	0.23	-0.18	-0.12
N = 40	Sig. (2-tailed)	0.53	1.00	0.16	0.28	0.46
NIF	Pearson Correlation	0.23	0.35	0.25	0.26	0.38
N = 40	Sig. (2-tailed)	0.15	0.03	0.13	0.11	0.02
PEForce	Pearson Correlation	0.30	0.21	-0.10	-0.09	0.24
N = 40	Sig. (2-tailed)	0.06	0.18	0.55	0.57	0.14
ACT FVC	Pearson Correlation	1.00	0.79	0.25	0.28	0.41
N = 40	Sig. (2-tailed)	.	0.00	0.13	0.08	0.01
ACT FEV1	Pearson Correlation	0.79	1.00	0.71	0.43	0.57
N = 40	Sig. (2-tailed)	0.00	.	0.00	0.01	0.00
ACT FEF_{25-75}	Pearson Correlation	0.25	0.71	1.00	0.29	0.25
N = 40	Sig. (2-tailed)	0.13	0.00	.	0.07	0.12
ACT PEFlow	Pearson Correlation	0.28	0.43	0.29	1.00	0.53
N = 40	Sig. (2-tailed)	0.08	0.01	0.07	.	0.00
ACT MVV	Pearson Correlation	0.41	0.57	0.25	0.53	1.00
N = 40	Sig. (2-tailed)	0.01	0.00	0.12	0.00	.
REL FVC	Pearson Correlation	0.95	0.72	0.16	0.20	0.41
N = 40	Sig. (2-tailed)	0.00	0.00	0.31	0.22	0.01
REL FEV1	Pearson Correlation	0.72	0.96	0.69	0.37	0.58
N = 40	Sig. (2-tailed)	0.00	0.00	0.00	0.02	0.00
REL FEF_{25-75}	Pearson Correlation	0.19	0.68	0.99	0.25	0.23
N = 40	Sig. (2-tailed)	0.24	0.00	0.00	0.13	0.15
REL PEFlow	Pearson Correlation	0.17	0.33	0.21	0.97	0.52
N = 40	Sig. (2-tailed)	0.31	0.04	0.19	0.00	0.00
REL MVV	Pearson Correlation	0.27	0.44	0.16	0.44	0.96
N = 40	Sig. (2-tailed)	0.09	0.00	0.31	0.00	0.00
% FVC	Pearson Correlation	0.30	0.10	-0.22	-0.16	0.18
N = 40	Sig. (2-tailed)	0.06	0.55	0.18	0.31	0.27
% FEV1	Pearson Correlation	0.19	0.40	0.30	0.02	0.36
N = 40	Sig. (2-tailed)	0.24	0.01	0.06	0.92	0.02
% FEF_{25-75}	Pearson Correlation	0.02	0.50	0.88	0.12	0.17
N = 40	Sig. (2-tailed)	0.89	0.00	0.00	0.46	0.28
% PEFlow	Pearson Correlation	-0.09	0.16	0.12	0.77	0.53
N = 40	Sig. (2-tailed)	0.58	0.31	0.45	0.00	0.00
% MVV	Pearson Correlation	0.12	0.26	0.04	0.26	0.84
N = 40	Sig. (2-tailed)	0.46	0.11	0.82	0.10	0.00
MILS WK	Pearson Correlation	0.16	0.18	0.30	-0.17	-0.15
N = 20	Sig. (2-tailed)	0.49	0.46	0.20	0.48	0.52
YRS RUN	Pearson Correlation	-0.41	-0.37	-0.11	-0.33	-0.36
N = 20	Sig. (2-tailed)	0.07	0.11	0.64	0.16	0.12
MARATH	Pearson Correlation	0.52	0.32	0.07	-0.06	0.18
N = 20	Sig. (2-tailed)	0.02	0.17	0.77	0.79	0.45
10K PR	Pearson Correlation	-0.09	-0.15	-0.22	0.28	0.21
N = 20	Sig. (2-tailed)	0.70	0.53	0.36	0.23	0.37
5K PR	Pearson Correlation	-0.06	-0.12	-0.12	0.33	0.15
N = 20	Sig. (2-tailed)	0.79	0.60	0.62	0.15	0.52
Correlation is significant at the 0.01 level (2-tailed).						
Correlation is significant at the 0.05 level (2-tailed).						

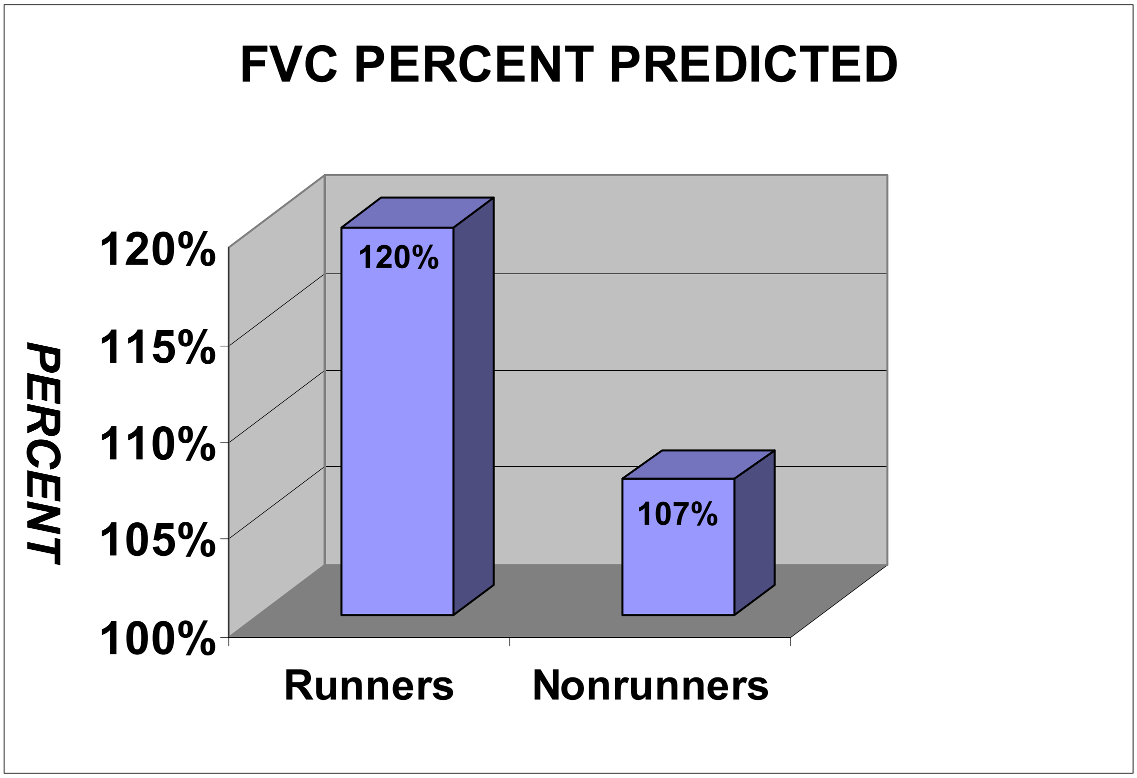
Correlation Matrix

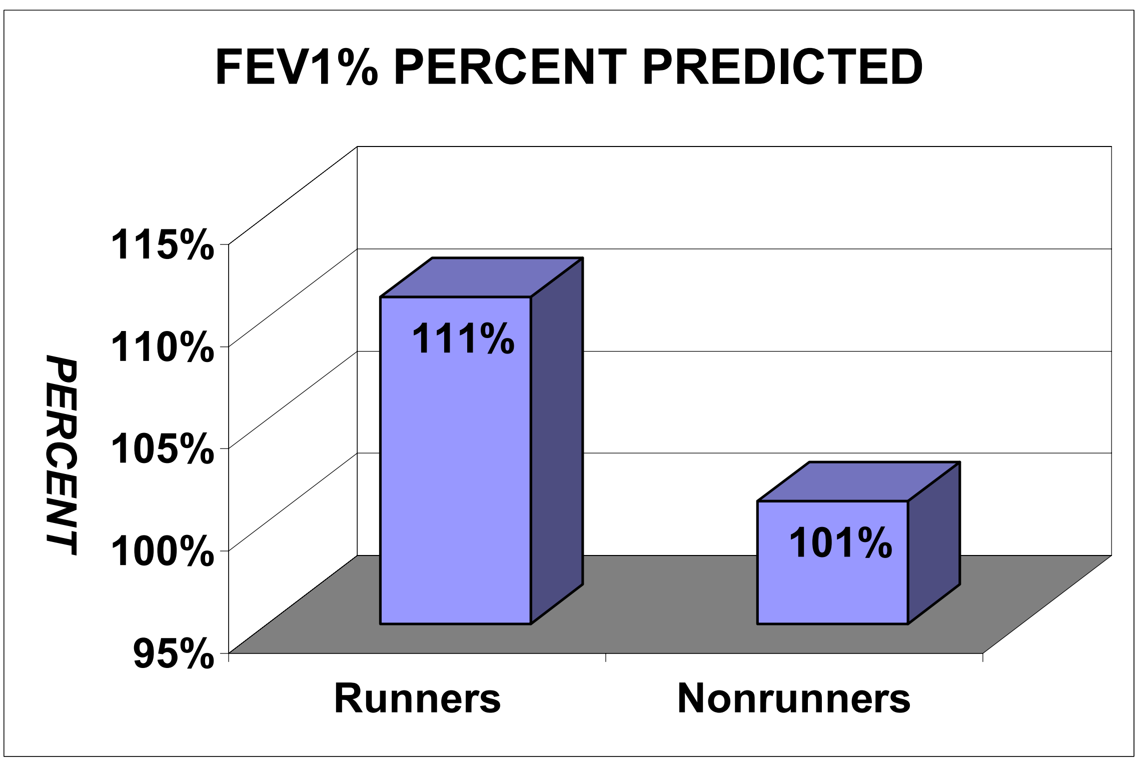
		RELATIVE FVC	RELATIVE FEV1	RELATIVE FEF_{25-75}	RELATIVE PEFlow	RELATIVE MVV
SUBJECT	Pearson Correlation	-0.26	-0.16	0.08	-0.17	-0.38
N = 40	Sig. (2-tailed)	0.11	0.34	0.62	0.29	0.02
AGE	Pearson Correlation	-0.26	-0.26	-0.20	-0.09	-0.05
N = 40	Sig. (2-tailed)	0.11	0.11	0.21	0.58	0.78
HEIGHT	Pearson Correlation	0.21	0.20	0.18	0.10	-0.14
N = 40	Sig. (2-tailed)	0.19	0.22	0.28	0.53	0.38
WEIGHT	Pearson Correlation	-0.10	0.01	0.23	-0.17	-0.20
N = 40	Sig. (2-tailed)	0.54	0.96	0.15	0.30	0.22
BMI	Pearson Correlation	-0.22	-0.09	0.19	-0.26	-0.18
N = 40	Sig. (2-tailed)	0.17	0.56	0.25	0.11	0.27
NIF	Pearson Correlation	0.15	0.28	0.21	0.20	0.30
N = 40	Sig. (2-tailed)	0.36	0.08	0.20	0.22	0.06
PEForce	Pearson Correlation	0.26	0.17	-0.13	-0.16	0.19
N = 40	Sig. (2-tailed)	0.11	0.30	0.44	0.34	0.23
ACT FVC	Pearson Correlation	0.95	0.72	0.19	0.17	0.27
N = 40	Sig. (2-tailed)	0.00	0.00	0.24	0.31	0.09
ACT FEV1	Pearson Correlation	0.72	0.96	0.68	0.33	0.44
N = 40	Sig. (2-tailed)	0.00	0.00	0.00	0.04	0.00
ACT FEF_{25-75}	Pearson Correlation	0.16	0.69	0.99	0.21	0.16
N = 40	Sig. (2-tailed)	0.31	0.00	0.00	0.19	0.31
ACT PEFlow	Pearson Correlation	0.20	0.37	0.25	0.97	0.44
N = 40	Sig. (2-tailed)	0.22	0.02	0.13	0.00	0.00
ACT MVV	Pearson Correlation	0.41	0.58	0.23	0.52	0.96
N = 40	Sig. (2-tailed)	0.01	0.00	0.15	0.00	0.00
REL FVC	Pearson Correlation	1.00	0.74	0.14	0.15	0.35
N = 40	Sig. (2-tailed)	.	0.00	0.38	0.34	0.03
REL FEV1	Pearson Correlation	0.74	1.00	0.69	0.33	0.51
N = 40	Sig. (2-tailed)	0.00	.	0.00	0.04	0.00
REL FEF_{25-75}	Pearson Correlation	0.14	0.69	1.00	0.20	0.18
N = 40	Sig. (2-tailed)	0.38	0.00	.	0.21	0.28
REL PEFlow	Pearson Correlation	0.15	0.33	0.20	1.00	0.50
N = 40	Sig. (2-tailed)	0.34	0.04	0.21	.	0.00
REL MVV	Pearson Correlation	0.35	0.51	0.18	0.50	1.00
N = 40	Sig. (2-tailed)	0.03	0.00	0.28	0.00	.
% FVC	Pearson Correlation	0.53	0.28	-0.15	-0.04	0.34
N = 40	Sig. (2-tailed)	0.00	0.08	0.34	0.82	0.03
% FEV1	Pearson Correlation	0.39	0.59	0.38	0.13	0.50
N = 40	Sig. (2-tailed)	0.01	0.00	0.02	0.42	0.00
% FEF_{25-75}	Pearson Correlation	0.02	0.56	0.91	0.12	0.18
N = 40	Sig. (2-tailed)	0.89	0.00	0.00	0.48	0.27
% PEFlow	Pearson Correlation	-0.06	0.22	0.14	0.85	0.58
N = 40	Sig. (2-tailed)	0.73	0.18	0.40	0.00	0.00
% MVV	Pearson Correlation	0.23	0.36	0.07	0.35	0.92
N = 40	Sig. (2-tailed)	0.15	0.02	0.68	0.03	0.00
MILS WK	Pearson Correlation	0.19	0.21	0.32	-0.18	-0.13
N = 20	Sig. (2-tailed)	0.42	0.38	0.16	0.46	0.60
YRS RUN	Pearson Correlation	-0.43	-0.36	-0.09	-0.29	-0.31
N = 20	Sig. (2-tailed)	0.06	0.12	0.70	0.21	0.18
MARATH	Pearson Correlation	0.53	0.29	0.04	-0.13	0.11
N = 20	Sig. (2-tailed)	0.02	0.22	0.87	0.59	0.64
10K PR	Pearson Correlation	-0.19	-0.23	-0.25	0.23	0.18
N = 20	Sig. (2-tailed)	0.41	0.32	0.28	0.32	0.46
5K PR	Pearson Correlation	-0.17	-0.21	-0.16	0.28	0.11
N = 20	Sig. (2-tailed)	0.48	0.37	0.51	0.23	0.64
Correlation is significant at the 0.01 level (2-tailed).						
Correlation is significant at the 0.05 level (2-tailed).						

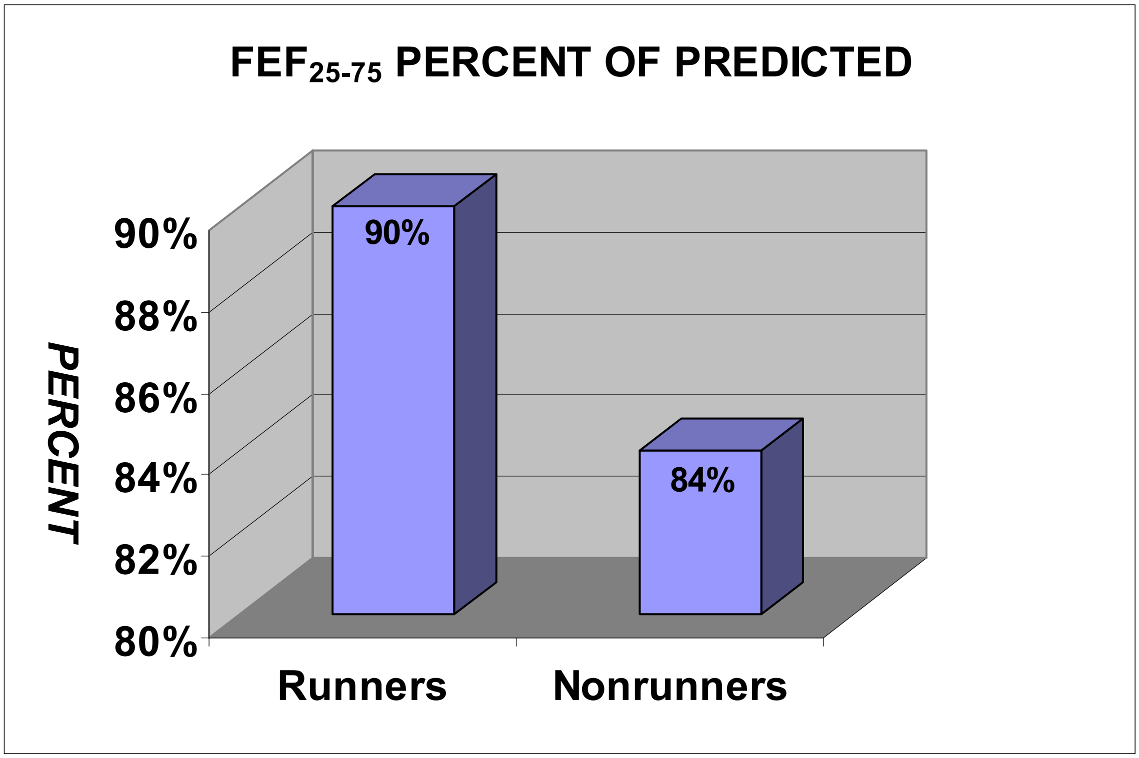
Correlation Matrix

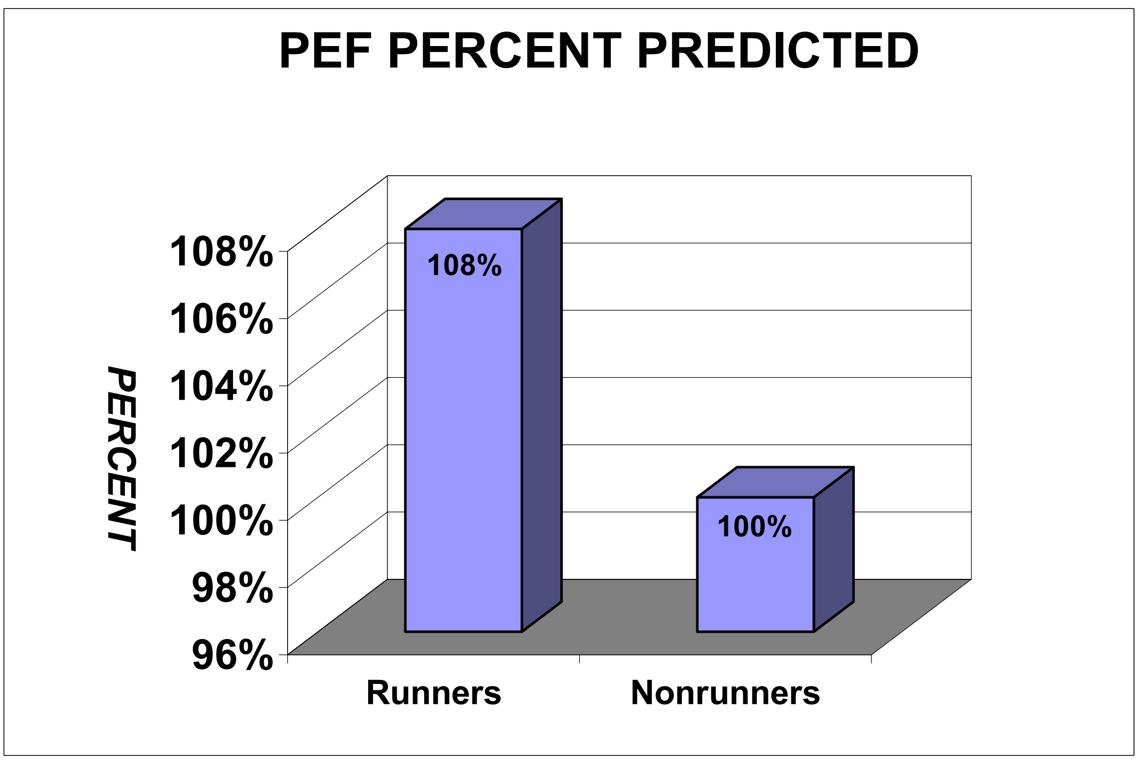
		% PRED FVC	% PRED FEV1	% PRED $FEF_{25\text{-}75}$	% PRED PEFlow	% PRED MVV
SUBJECT	Pearson Correlation	-0.43	-0.36	-0.09	-0.19	-0.42
N = 40	Sig. (2-tailed)	0.01	0.02	0.60	0.24	0.01
AGE	Pearson Correlation	0.24	0.26	0.04	0.09	0.20
N = 40	Sig. (2-tailed)	0.13	0.11	0.79	0.57	0.22
HEIGHT	Pearson Correlation	-0.59	-0.54	-0.03	-0.15	-0.30
N = 40	Sig. (2-tailed)	0.00	0.00	0.84	0.36	0.06
WEIGHT	Pearson Correlation	-0.53	-0.43	0.04	-0.28	-0.30
N = 40	Sig. (2-tailed)	0.00	0.01	0.79	0.08	0.06
BMI	Pearson Correlation	-0.36	-0.27	0.06	-0.28	-0.23
N = 40	Sig. (2-tailed)	0.02	0.09	0.73	0.08	0.15
NIF	Pearson Correlation	-0.11	0.04	0.11	0.18	0.19
N = 40	Sig. (2-tailed)	0.50	0.82	0.50	0.27	0.23
PEForce	Pearson Correlation	0.18	0.13	-0.09	-0.06	0.17
N = 40	Sig. (2-tailed)	0.27	0.41	0.58	0.72	0.30
ACT FVC	Pearson Correlation	0.30	0.19	0.02	-0.09	0.12
N = 40	Sig. (2-tailed)	0.06	0.24	0.89	0.58	0.46
ACT FEV1	Pearson Correlation	0.10	0.40	0.50	0.16	0.26
N = 40	Sig. (2-tailed)	0.55	0.01	0.00	0.31	0.11
ACT $FEF_{25\text{-}75}$	Pearson Correlation	-0.22	0.30	0.88	0.12	0.04
N = 40	Sig. (2-tailed)	0.18	0.06	0.00	0.45	0.82
ACT PEFlow	Pearson Correlation	-0.16	0.02	0.12	0.77	0.26
N = 40	Sig. (2-tailed)	0.31	0.92	0.46	0.00	0.10
ACT MVV	Pearson Correlation	0.18	0.36	0.17	0.53	0.84
N = 40	Sig. (2-tailed)	0.27	0.02	0.28	0.00	0.00
REL FVC	Pearson Correlation	0.53	0.39	0.02	-0.06	0.23
N = 40	Sig. (2-tailed)	0.00	0.01	0.89	0.73	0.15
REL FEV1	Pearson Correlation	0.28	0.59	0.56	0.22	0.36
N = 40	Sig. (2-tailed)	0.08	0.00	0.00	0.18	0.02
REL $FEF_{25\text{-}75}$	Pearson Correlation	-0.15	0.38	0.91	0.14	0.07
N = 40	Sig. (2-tailed)	0.34	0.02	0.00	0.40	0.68
REL PEFlow	Pearson Correlation	-0.04	0.13	0.12	0.85	0.35
N = 40	Sig. (2-tailed)	0.82	0.42	0.48	0.00	0.03
REL MVV	Pearson Correlation	0.34	0.50	0.18	0.58	0.92
N = 40	Sig. (2-tailed)	0.03	0.00	0.27	0.00	0.00
% FVC	Pearson Correlation	1.00	0.79	0.01	0.10	0.47
N = 40	Sig. (2-tailed)	.	0.00	0.95	0.56	0.00
% FEV1	Pearson Correlation	0.79	1.00	0.53	0.31	0.59
N = 40	Sig. (2-tailed)	0.00	.	0.00	0.05	0.00
% $FEF_{25\text{-}75}$	Pearson Correlation	0.01	0.53	1.00	0.12	0.16
N = 40	Sig. (2-tailed)	0.95	0.00	.	0.48	0.31
% PEFlow	Pearson Correlation	0.10	0.31	0.12	1.00	0.52
N = 40	Sig. (2-tailed)	0.56	0.05	0.48	.	0.00
% MVV	Pearson Correlation	0.47	0.59	0.16	0.52	1.00
N = 40	Sig. (2-tailed)	0.00	0.00	0.31	0.00	.
MILS WK	Pearson Correlation	0.30	0.33	0.44	-0.18	-0.12
N = 20	Sig. (2-tailed)	0.20	0.15	0.05	0.46	0.63
YRS RUN	Pearson Correlation	-0.06	-0.05	0.05	-0.15	-0.05
N = 20	Sig. (2-tailed)	0.81	0.84	0.83	0.54	0.85
MARATH	Pearson Correlation	0.26	0.10	-0.04	-0.11	0.09
N = 20	Sig. (2-tailed)	0.28	0.69	0.86	0.65	0.70
10K PR	Pearson Correlation	-0.20	-0.25	-0.25	0.14	0.06
N = 20	Sig. (2-tailed)	0.40	0.29	0.29	0.56	0.80
5K PR	Pearson Correlation	-0.22	-0.25	-0.14	0.14	-0.05
N = 20	Sig. (2-tailed)	0.35	0.28	0.55	0.56	0.85
Correlation is significant at the 0.01 level (2-tailed).						
Correlation is significant at the 0.05 level (2-tailed).						

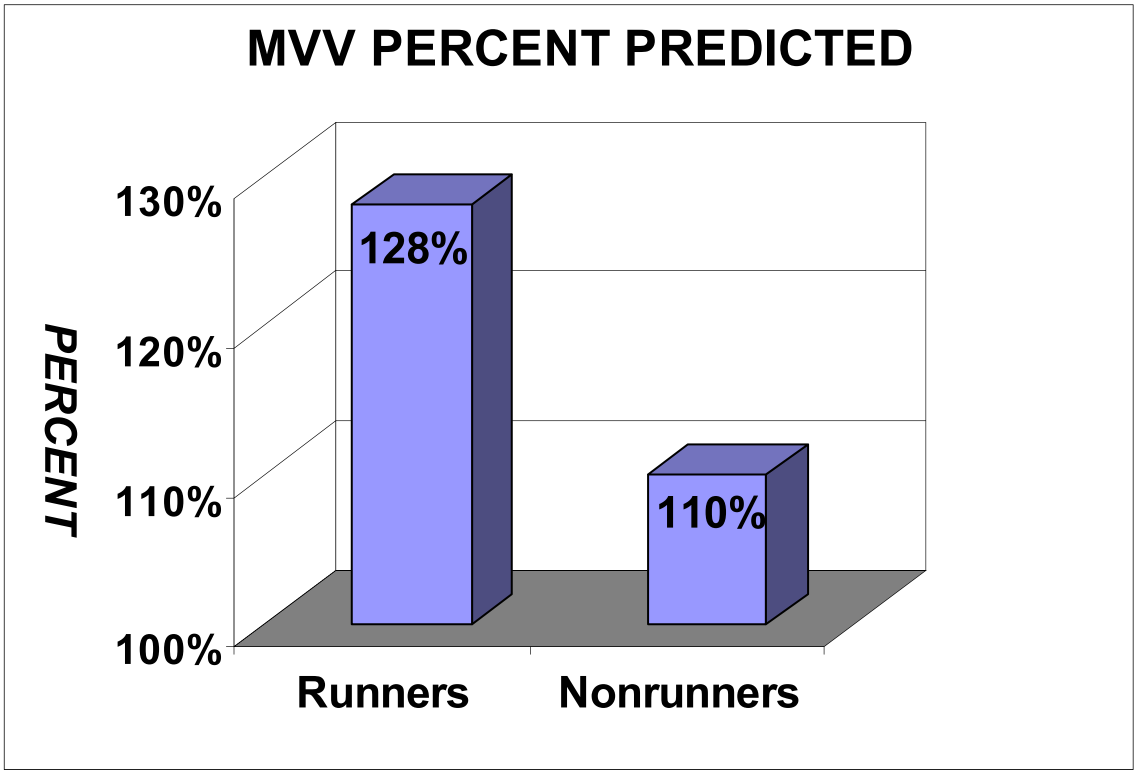
APPENDIX H


FVC PERCENT PREDICTED
PERCENT
120%
115%
110%
105%
100%
120%
107%
Runners
Nonrunners


FEV1% PERCENT PREDICTED
PERCENT
115%
110%
105%
100%
95%
111%
101%
Runners
Nonrunners


FEF25-75 PERCENT OF PREDICTED
PERCENT
90%
88%
86%
84%
82%
80%
90%
84%
Runners
Nonrunners


PEF PERCENT PREDICTED
PERCENT
108%
106%
104%
102%
100%
98%
96%
108%
100%
Runners
Nonrunners


MVV PERCENT PREDICTED
PERCENT
130%
120%
110%
100%
128%
110%
Runners
Nonrunners

VITA

James Buras was born February 20, 1952 in New Orleans, Louisiana. He is a graduate of West Jefferson High School of Harvey, Louisiana. He graduated from Louisiana State University, School of Allied Health Professions New Orleans in 1989 with a Bachelor of Science Degree in Cardiopulmonary Science. He has worked as a Registered Respiratory Therapist and Certified Pulmonary Function Technologist for the previous 16 years. He will graduate from the University of New Orleans with a Master of Arts in Human Performance and Health Promotion with an emphasis in exercise physiology on December 17, 2004.